Journal of Biogeography

Multiple stressors facilitate the spread of a non-indigenous bivalve in the Mediterranean Sea

Journal:	*Journal of Biogeography*
Manuscript ID	JBI-16-0620.R2
Manuscript Type:	Research Paper
Date Submitted by the Author:	n/a
Complete List of Authors:	Sarà, Gianluca; University of Palermo, Earth and Marine Science Porporato, Erika; Università di Palermo, Dipartimento di Scienze della Terra e del Mare; Ca' Foscari University of Venice, Department of Environmental Sciences Mangano, Maria; Università di Palermo, Dipartimento di Scienze della Terra e del Mare Mieszkowska, Nova; Marine Biological Association of the U.K., Biodiversity and Ecology; University of Liverpool, Department of Earth Ocean and Ecological Sciences
Key Words:	Climate change, Habitat fragmentation, Maxent, Non-indigenous species, Regional Climate Model, Sensitivity analysis, Species Distribution Model

The Marine Biological Association

Established 1884, incorporated by Royal Charter 2013

Patron: HRH The Prince Philip, Duke of Edinburgh
President: Professor Sir John Beddington, CMG FRS
Director: Professor Colin Brownlee

The Laboratory
Citadel Hill
Plymouth
PL1 2PB
United Kingdom

tel: **+44 (0)1752 633207**
fax: **+44 (0)1752 633102**
email: **sec@mba.ac.uk**
www.mba.ac.uk

03/11/2017

Dear Prof. Ladle

Manuscript resubmission JBI-16-0620 Multiple stressors facilitate the spread of a non-indigenous bivalve in the Mediterranean Sea.

Please extend our thanks to the reviewers for their detailed comments on our manuscript. We have addressed all of their suggested edits that have helped to improve the structure and text of the revised manuscript. Our responses are written below each individual comment in the Editor's comments to the author section below.

Yours sincerely

Dr Nova Mieszkowska

EDITOR'S COMMENTS TO AUTHOR

Editor: Chapman, Daniel

Comments to the Author:

Many thanks for your revised manuscript, which has addressed most of the previous reviewer comments. In your revision please address the outstanding comment, including visualising the responses and pairwise interactions (this could probably go in the Appendices).

I also suggest improving the presentation by replacing Table 1 (which is very valuable but overly detailed) with a 'heat map' figure showing the direction and magnitude of

changes with a colour scale. You could keep the layout of the table, but just colour the cells.
To make space for this, I suggest plotting maps for only one of either 2030 or 2050 (Figs. 3-6) and putting the other year's maps in the Appendices.
Reply: Many thanks, we agreed and worked on it accordingly. Pairwise interactions are now reported in Appendix 2 Figs. A4, A5, Table 1 is with colours, we preferred to leave in the MS both 2030 and 2050 maps.

A minor comment from me - please consider changing the phrase 'a latere', in the Abstract. To my knowledge it is not standard English.
Reply: Many thanks, we agreed and changed it accordingly.

REVIEWER COMMENTS TO AUTHOR
Referee 1
Second review of the manuscript by Sarà entitled "Multiple stressors facilitate the spread of a non-indigenous bivalve in the Mediterranean Sea". The manuscript is generally improved, although some issues were not satisfactorily tackled. It would be far easier to map author changes if they provide the lines where the modifications were performed.

Main comments
Introduction
L140 This sentence is still confusing. Why the native species increase with the invasive species presence? Through which mechanism? Is it facilitation? Habitat improvement? Please, clarify.
Reply: Yes, sorry it wasn't clear. The sentence is referring to information reported by other Authors in literature, we now added the specific references to this sentence and we indicated the presence of a more accurate list in the table presented in Appendix 1. The cited Authors suppose an increase in local species diversity, therefore we were moved from your same curiosity, and also considering the scanty amount of only qualitative papers already published focusing on this aspect, we are now trying to test it in the field (data analyses are in progress).

Methods
L 257-260 Regarding comments on the first version, I suggest to add the spatial resolution (1km) used to the main text and clarify what is exactly "threshold equal training sensitivity and specificity"
Reply: Agree and added (**L 245-246** and **L 256-265**).

Results
Comment. I miss a section in the results section where the authors explain the relationship of each predictive variable with HIS (positive, negative relationship, etc., lineal/unimodal, etc.). I recommend plotting the response of HSI to pairwise stressor combinations to show potential interactions. Currently, it is not possible to infer any of them through the information provided.

Feld et al. (2016) provides a comprehensive description of how to analyse and communicate multi-stressor interactions.
L345-353 should be appropriately reviewed
Feld, C. K., Segurado, P., & Gutiérrez-Cánovas, C. (2016). Analysing the impact of multiple stressors in aquatic biomonitoring data: A Œcookbook¹with applications in R. Science of the Total Environment.

Reply: We agree with the referee and we have added the Figure A4 and A5 in the Supplementary materials Appendix 2 analysing the HSI 2010 relationships with the environmental variables. First, we have added Figure A4, a graph produced by Maxent, representing the response of *B. pharaonis* to each variable considered. Moreover, we have added the percentage contribution of each variable within each graph. Second, following the method described in Feld et al., 2016, we have added Figure A5 in order to show potential interactions, representing the response of HSI to pairwise stressor combinations (**L 294-296** and **L 345-347** in the main text). Regarding the L345-353, we agreed with the referee and we have changed it accordingly.

Comment. The authors may consider showing the marginal responses of *B. pharaonis* to each of the environmental predictors in the model for 2010 (i.e. the modeled probability of occurrence versus a range of values for a given environmental variable, keeping all other variables constant, see Azzurro et al., 2013 Biol. Invasions for an example). this would facilitate the identification of potential nonlinear responses (e.g. to productivity, see below).
Reply: We agreed and we have added the partial dependence curves of the 2010 model in the Supplementary materials Appendix 2, Figure A4. The importance of each variable was reported within the graph and hence we have removed the Table A2.

Minor comments
L84: Do the authors mean “multiple anthropogenic factors”?
Reply: Agreed, checked and changed accordingly.

L277: I guess HSI was derived from the Maxent model. Authors should be more explicit here and help reader to follow their methodology.
Reply: Agree and added (**L 253-256**)

L308-315: These lines seem to be more appropriate for the discussion.
Reply: Agreed, checked and changed accordingly.

L317 It could be more informative to say: “Forecasted habitat suitability”.
Reply: Agreed, checked and changed accordingly.

L334 change “HIS” by “HIS”.
Reply: Agreed, checked and changed accordingly.

A final tip from the Editorial Office: having dealt with all the comments above, please work systematically through the attached author checklist prior to re-submitting your paper. Failure to do so is likely to result in the paper being returned to your author centre.

Article Type: Original Article

Running head: Multiple stressor impacts on non-indigenous species

Multiple stressors facilitate the spread of a non-indigenous bivalve in the Mediterranean Sea

Gianluca Sarà[1], Erika M.D. Porporato[2], M. Cristina Mangano[1,3] and Nova Mieszkowska[4,5*]

[1]Dipartimento di Scienze della Terra e del Mare, Università di Palermo, V.le delle Scienze - Ed. 16 - 90128 Palermo, Italy

[2]Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, Via Torino 155 - 30170 Venezia, Mestre, Italy

[3]Consorzio Nazionale Interuniversitario per le Science del Mare (CoNISMa), Piazzale Flaminio 9, 00196 - Roma, Italy

[4]The Marine Biological Association of the UK, Citadel Hill, Plymouth, PL1 2PB, UK. nova@mba.ac.uk Tel: +44 1752633333. *To whom correspondence should be addressed.

[5]Department of Earth, Ocean and Ecological Sciences, School of Environmental Sciences, University of Liverpool, Nicholson Building, Brownlow Street, Liverpool, L69 3GP, UK

Word count abstract: 381

Word count main body of text: 7999

Abstract

Aim: The introduction of non-indigenous species (NIS) via man-made corridors connecting previously disparate oceanic regions is increasing globally. The environmental and anthropogenic factors facilitating invasion dynamics and their interactions are, however, still largely unknown. This study compiles and inputs available data for the NIS bivalve *Brachidontes pharaonis* across the invaded biogeographic range in the Mediterranean basin into a species distribution model to predict future spread across the Mediterranean Sea under a range of marine scenarios.

Location: Mediterranean Sea.

Methods: A systematic review produced the largest presence database ever assembled to inform the selection of biological, chemical and physical factors linked to the spread of the NIS bivalve *B. pharaonis* through the Suez Canal into the Mediterranean basin. After comparing methodological approaches we elected to carry out a sensitivity analysis to simulate current and future trophic and salinity scenarios. A species distribution model was then run to determine key drivers of invasion, quantify interactive impacts arising from a range of trophic states, salinity conditions and climatic scenarios, and forecast future trajectories for the spread of NIS into new regions under multiple-parameter scenarios, based on the main factors identified from the systematic review.

Results: Impacts on invasion trajectory arising from climate change and interactions with increasing salinity from the new opening of the Suez Canal were the primary drivers of expansion across the basin, the effects of which were further enhanced by eutrophication. Predictions of the current distribution were most accurate when multiple stressors were used to drive the model. An Habitat Suitability Index developed at a subcontinental scale from model outputs identified novel favourable conditions for future colonization at specific locations under 2030 and 2050 climatic scenarios.

Main Conclusions: Future expansion of *B. pharaonis* will be enhanced by climate-facilitated increased sea temperature, interacting with increasing pressures from salinity and eutrophication. The spatially-explicit risk output maps of invasions, which also function as risk/pest maps, represent a powerful visual product for use in communication of the spread of NIS and decision-support tools for scientists and policymakers. The observed distribution pattern and driving processes, as well the suggested approach, can be applied to other NIS species and regions by providing novel forecasts of species occurrences under future multiple stressor scenarios, and the location of suitable recipient habitats with respect to anthropogenic and environmental parameters.

Keywords: Climate change, Habitat fragmentation, Maxent, Non-indigenous species, Regional Climate Model, Sensitivity analysis, Species Distribution Model

Introduction

Climate change is driving poleward range shifts in marine species across a wide range of benthic taxa (Mieszkowska *et al*., 2006; Helmuth *et al*., 2006; Lima *et al*., 2007; Poloczanska *et al*., 2013; Mieszkowska *et al*., 2014) and is thought to be exacerbating the invasion success of Non-Indigenous Species (NIS) (Pederson *et al*., 2011). Climate change exerts a significant and growing impact on global biodiversity and potential 'globalization' of marine fauna and flora resulting in biodiversity loss, alteration of ecosystem function and degradation of ecosystem services (Walther *et al*., 2009; Bradley *et al*., 2010; Gallien *et al*., 2010; Sorte *et al*., 2010; Vilà *et al*., 2011; Marzloff *et al.,* 2016; Pecl *et al.,* 2017). The majority of marine NIS that have successfully colonized new regions beyond those accessible *via* natural modes of dispersal are thought to proliferate in their introduced ranges due to their greater tolerances for one or more environmental parameters when compared to native species present within the invaded community (Sorte *et al*., 2010; Lenz *et al*., 2011; Zerebeki & Sorte 2011). Advances in our ability to track biogeographic range shifts and invasions have increased awareness of the enormous complexity of environmental and anthropogenic processes involved in biological invasions in a changing world. Beyond a simplistic, unilateral response to warming of the global oceans, scientists must seek new, integrated approaches to predict future biogeographic shifts of NIS (Burrows *et al*., 2014). The development of predictive models that can be run for a range of multiple anthropogenic factors (hereafter termed stressors; *sensu* Gunderson *et al*., 2016) scenarios will increase the accuracy of the quantitative forecasts for ecological and economic cost of invasion, and provide useful guidance for planning management or control strategies that form part of the mitigation and adaptation management processes (Ritcher *et al*., 2013; Hamaoui-Laguel *et al*., 2015; Chapman *et al*., 2016).

A specific mode of invasion is that observed for 'Lessepsian' invasive species, those utilizing the Suez Canal (a manmade corridor between previously unconnected seas) as a pathway to colonize new environments far removed from their origin. This manmade construction connects the Indo-Pacific and the Red Sea with the Mediterranean Sea and is termed the "Eastern door", through which NIS invade the Mediterranean basin by planktonic larvae in a "stepping stone" fashion (as traditionally assumed) and via shipping vectors of hull fouling and ballast water transport (Galil *et al*., 2015). This situation is by no means unique, with manmade corridors providing connective pathways for marine invasions around the world, including the Panama Canal, White Sea – Baltic Sea Canal, Kiel Canal and Danube-Black Sea Canal. Shipping and shipping-related constructions are thus contributing to the movement of marine species around the world, shaping the origin, frequency and magnitude of species movements by providing new introduction routes for Lessepsian invasions (Hulme 2009; Katsanevakis *et al*., 2014; Ojaveer *et al*., 2014).

The key to a successful invasion is the presence of suitable habitats (*sensu* resistance hypothesis - Ruiz *et al*., 2000) with respect to physical, chemical and trophic conditions in those areas where new NIS propagules arrive (Boudouresque *et al*., 2004; Hulme *et al*., 2008; Galil 2009; Sarà *et al*., 2013). Climatic and anthropogenic forcing of the marine environment, coupled with an increase in shipping traffic from the Levantine Basin are thought to have amplified both the Habitat Suitability (HS) and the propagule pressure for NIS within the Mediterranean in recent years (Katsanevakis *et al*., 2014), however, this has not been quantitatively investigated for most invasive species recorded within the Mediterranean Sea.

Here we investigate how anthropogenically driven changes to the marine environment, including those related to changes driven by manmade canals connecting separate seas, may exacerbate the existing impacts of NIS on native species, communities and ecosystems, and alter their trajectory of future spread. We use the recent expansion of the Suez Canal *via* a second parallel seaway (officially inaugurated on the 06/08/2015; http://newcanal.suezcanal.gov.eg) as a case study system to test the impacts of multiple anthropogenic stressors on the invasion trajectory of a Lessepsian NIS within the Mediterranean Sea, and address how this type of infrastructure can result in wider implications for both Lessepsian and global species invasions.

The second Suez Canal waterway will have a large impact on the biological (*e.g.* the increase of the propagule pressure for a wide variety of species), physical and chemical characteristics of the Mediterranean Sea. Biotic changes have already occurred as a result of several previous enlargements of the existing canal, resulting in environmental changes initiated in the Eastern basin and propagating across the entire basin (Katsanevakis *et al*., 2014). Invasion dynamics are predicted to accelerate with exposure to these human- (*e.g.* eutrophication; Nixon 2009) and climate-related factors (*e.g.* modification of temperature and wind-driven hydrodynamics; Compton *et al.,* 2010; Pachauri *et al*., 2014; Adloff *et al*., 2015) which are already driving range shifts in the distributions of native species, altering community structure, diversity and resilience, thus favouring biological invasions (Parmesan & Yohe 2003). We predict that these drivers will interact with those deriving from the new Suez Canal opening, exposing Mediterranean biodiversity to large modifications of chemical and physical properties.

The focal species of this study is the Lessepsian mussel, *Brachidontes pharaonis* (Bivalvia, Fischer 1870), a bivalve classified as a “pest model NIS” (Galil 2009). *B. pharaonis* is widely reported to be invading the Mediterranean, however, knowledge of the ecology and physiology of this species are lacking in comparison with other marine NIS. *B. pharaonis* occurs on littoral rocky habitat. It has a planktonic larval phase, and a protracted, year-round reproductive cycle. This species has a wide thermotolerance range (9-31°C) and can tolerate salinities from 35-53psu, traits typical of most Lessepsian NIS (Sarà *et al*., 2008;

Katsanevakis *et al*., 2014; to see also references listed in Appendix 1). *B. pharaonis* exerts strong local-scale effects on hard substrata biodiversity by creating biogenic habitat that promotes local species richness, outcompeting native species for resources and space (Safriel *et al.,* 1980; 1988; Bonnici *et al.,* 2012; to see also references listed in Appendix 1). The biology and invasion ecology of this species is typical of NIS with respect to wide ecophysiological tolerance ranges for environmental parameters including temperature, salinity and water pH, making *B. pharaonis* a suitable model species with which to study how human and climate-related factors will drive biological invasions from the present day to 2050.

Whilst recent approaches based on mechanistic trait-based models (*e.g.* Sarà *et al.,* 2013) are able to reliably predict the current spatial distribution of NIS, they require huge amounts of data in order to provide reliable predictions of NIS spread in the future when assessing the effects of environmental change, including climate change. Unfortunately, the investigation of impacts arising from multiple anthropogenic factors is still far from the application's range of mechanistic trait-based modelling. In contrast, to provide a valuable, effective and immediate tool for decision making involved in NIS management, we employed an integrated classical correlative approach to NIS modelling but bringing the novelty of the interaction between multiple stressors (salinity and temperature as proxies of tropicalisation, and eutrophication as a proxy of local urbanization) tested through a set of sensitivity analyses. Thus we derived reliable and exploitable information to: *i)* generate risk maps of future biological invasions (*sensu* Hulme 2009) useful to feed strategic and tactical pest management decisions; *ii)* forecast relevant outcomes to inform scientists and managers on ecological and socio-economic potential impacts generated by ongoing invasions; *iii)* fulfil emergent regulations, policy drivers and directives in the framework of European Parliament and Council; and *iv)* provide strategies for managing NIS as part of a realistic, integrated, ecosystem-based approach, which is a major challenge for the scientific community, stakeholders and decision makers.

Materials and methods

Literature search

An extensive literature analysis was completed *viz.* a systematic review, validated as a comprehensive, policy-neutral, transparent, reproducible, robust assessment and summary of available evidence to support biodiversity conservation and policy decision making on environmental issues (Gurevitch & Hedges 2001; Bilotta *et al*., 2014). The literature search was designed to investigate the past and present distribution of *B. pharaonis* across the Mediterranean basin and to identify factors potentially affecting its ability to colonise new habitats. The search was carried out using prominent or substantial keywords forming a simple search string ("*Brachidontes pharaonis*" AND "Mediterranean"). The search ranged from the year 1900 to the present day and was restricted to the Mediterranean region. The search string was entered into the following scientific computerised databases including: ISI Web of Sciences, Scopus, BioOne, CAB Abstracts, Aquatic Sciences and Fisheries Abstracts (since 1971), Directory of Open Access Journal and J-STOR. Additional general search engines were used (Google and Google Scholar) limiting the search for appropriate data to the Word, PDF and/or Excel documents and to the first 50 hits (CEE review guidelines, 2013; Mangano & Sarà 2017a,b; Mangano *et al.,* 2017). A hand search was also performed on the bibliographies of relevant review articles to identify any additional references. Data on presence records were searched for in specific database and information systems showing current and past distribution maps (*e.g.* shapefiles, polygons, points); Ocean Biogeographic Information System [http://www.iobis.org/]; Global Biodiversity Information Facility [http://www.gbif.org/]; AquaNIS [http://www.corpi.ku.lt/databases/index.php/aquanis];

DAISIE [http://www.europe-aliens.org], EASIN [http://easin.jrc.ec.europa.eu]; World Register of Introduced Marine Species [http://www.marinespecies.org/introduced/aphia]. Authors of relevant articles not readily available on-line were personally contacted via paper request, providing any missing data and unpublished material or further recommendations (search ended at 21/08/2015). Hits generated from the search were collated in a database, examined for relevance and critically appraised (Appendix 1). Data and evidence extraction from peer-review and grey literature were organised and synthesised according to specific criteria, *e.g.* geographic area, habitat preferences, associated species, with a complete list of the collated studies for each Mediterranean sector (Appendix 1). All quantitative information from each paper were extracted in order to draw up the most correct and precise picture of the ecological status of *B. pharaonis* in the Mediterranean basin and on the environmental parameters influencing its distribution.

Maxent modelling

Presence data that represented the current known distributions for *B. pharaonis* were extracted through the systematic review process and used to build the occurrence dataset for *B. pharaonis* within the Mediterranean basin. Data and evidence from the review process were used to populate a presence-only Maximum entropy (Maxent) species-distribution model (SDM) to forecast habitat suitability (Phillips *et al.,* 2006) for *B. pharaonis.* Maxent represents the most effective correlative modelling approach in context of SDM (Guisan & Zimmermann 2000), providing an important ecological tool for the prediction of NIS geographical distribution within the context of climate change (Elith & Leathwick 2009; Walther *et al*., 2009). These scenarios were used to forecast how the potential habitat suitability for *B. pharaonis* will vary across three trophic statuses (oligotrophication, no-change and eutrophication) in combination with 11 salinity conditions across a gradient from decreasing (from -0.1 to -0.5 psu), no-change to increasing salinity (from +0.1 to +0.5 psu) with respect to two climate scenarios (2030 and 2050; Med-Cordex Regional Climate Model, Representative Concentration Pathways 4.5). Trophic and salinity conditions have been simulated through sensitivity analyses, a very useful alternative tool to explore the robustness of models' outputs within an uncertain context (Payne *et al*., 2015).

The data collated from the systematic review were used to determine the geographical presence of *B. pharaonis* across the Mediterranean basin, to input into the Maxent modelling processes. The current distribution of *B. pharaonis* in the invasive range was modelled employing 98 presence records (Fig. 1) and 8 physical, chemical and biological variables selected after the collinearity tests (Variance Inflation Factor – VIF, Table A2 in Appendix 2).

Data cleaning was required to remove data duplicates and incorrect records. Sampling bias is a well-known factor influencing SDMs (Phillips *et al.,* 2009), leading to spatial autocorrelation of records and artificial spatial clusters of observations, violating the assumption of independence (Dormann *et al.,* 2007). This bias can be avoided by sampling one point *per* cluster in the environmental space, which was carried out using the software OccurrenceThinner (Verbruggen 2012). OccurrenceThinner identifies areas of high record density based on the species occurrence records and a two-dimensional kernel surface grid file representing the region of study to filter occurrence records (Verbruggen 2012; Verbruggen *et al.,* 2013). Ten pseudo-replicate datasets produced through OccurrenceThinner, each with reduced sampling bias were run in order to reduce densely sampled regions. After this procedure the occurrence dataset contained 98 unique presence records.

Environmental climatic NetCDF data (Network Common Data Form) were downloaded from the Med-CORDEX (Mediterranean Coordinated Regional Climate Downscaling Experiment) website (https://www.medcordex.eu/). NetCDF files were extracted and manipulated employing the Climate Data Operator (CDO) software (1.6.4

version; Max-Planck Institut für Meterologie). Layers of chlorophyll concentration data were obtained from Copernicus project (http://marine.copernicus.eu/). For the future scenarios, we assumed a magnitude of change in chlorophyll-a concentrations of +10%, coded as eutrophication scenario, and -10%, coded as oligotrophication scenarios (*sensu* Nixon 2009). Similarly, we generated 11 salinity scenarios: no change, 5 salinity decrease scenarios (from -0.1 to -0.5) and 5 salinity increase scenarios (from +0.1 to +0.5).

Prior to analysis, all the environmental data were rescaled at 1 km applying the nearest neighbour interpolation. Eight environmental variables were selected (Table A1 in Appendix 2) based on their biological relevance, as potential predictors of habitat distribution for *B. pharaonis*. Species distribution models were applied using Maxent software (version 3.3.3k; Phillips *et al*., 2006). The default settings including logistic output, regularization multiplier 1, and 10,000 background points were used. The model evaluation was carried out through the random test percentage, splitting the whole dataset in training (70%) and test data (30%), subsamples (equal to the number of observation) and 5000 iterations, using the easily interpretable logistic output format with habitat suitability values. Indeed, Maxent generates an estimate of species probability presence ranging from 0 (unsuitable habitat) to 1 (optimal habitat) representing the distribution in geographic space of suitable habitat (*i.e.*: Habitat Suitability Index - HSI) (Elith *et al*., 2006; Phillips & Dudík 2008). Subsample replicates from Maxent were used as proxies for different single-models to reach a consensus scenario, reduce model inter-variability and to avoid potentially compromising policy decisions. To construct current distributions, we converted the continuous suitability predictions to binary predictions using the “threshold equal training sensitivity and specificity” command in Maxent. The sensitivity is the probability that the model correctly predicts an observation (true positive rate), while specificity is the probability that a known absence is correctly predicted (true negative rate). This is the most reliable threshold allowing to minimise the absolute difference between sensitivity and specificity (Nenzén & Araújo 2011) and to balance the accuracy of areas correctly modeled as present and absent in the training and test data. Specifically, at this threshold the chance of missing suitable distribution and assigning unsuitable distribution is the same.

Subsequently, the performance model was assessed by calculating the Area Under the Curve (AUC) of the Receiver Operator Characteristic (ROC), a measure of discrimination capacity of generated models (Delong *et al.,* 1988). Models with an AUC of 0.5 corresponded to the expected performance of a random classifier, 0.7–0.8 are considered an acceptable prediction, 0.8–0.9 are excellent and >0.9 are outstanding (Hosmer & Lemeshow 1989).

Prior to running the models, all environmental data were remapped using the nearest neighbour interpolation, employing CDO in order to achieve the highest possible spatial resolution (1 km), with the same extent and spatial projection used for all variables. Subsequently, the entire environmental dataset was clipped with the Mediterranean coastline. Collinearity between predictors was tested applying the vifstep function from the usdm package in R (Naimi 2013) and the predictor variables were selected.

In order to assess the rate of expansion of *B. pharaonis* in response to recent and short-term future climate change, the models were run for the time-steps 2010, 2030 and 2050. For the future distribution models, 66 scenarios of salinity (11 scenarios) and chlorophyll-a concentration parameters (3 scenarios) were calculated and the obtained results were divided for the three principal Mediterranean basins: Eastern, Central and Western Mediterranean Sea. From these scenarios, HSI was derived for each time step across the Mediterranean Sea basin (Figs. 3 and 4) presented herein as geographical forecast maps according to the classical geographical division of the Mediterranean basin: the Eastern, the Central (Sicilian Channel, Ionian and Adriatic seas) and the Western (Tyrrhenian, Balearic and Alboran seas; Fig. 1). The percentage of variation of mean HSI was estimated in comparison to 2010 (Fig. 2), within the three considered Mediterranean basins (Eastern, Central and Western) for each of the 66 simulated scenarios, respectively for 2030 and 2050 under different trophic and salinity scenario (Table 1). The invasion risk of this species was tested by calculating the frequency of scenarios in which the HSI was greater than 0.7, in order to highlight the suitable areas for colonization under the possible future environmental states. Potential interactions between HSI and the environmental variables considered in 2010 were analysed in terms of absolute Pearson correlations and kernel density overlays (Feld *et al.*, 2016).

Results

Studies published on *B. pharaonis* during the 2000s (Fig. 1) show the introduced range of *B. pharaonis* spreading westwards throughout the Mediterranean Sea, following the anticlockwise direction taken by most Lessepsian NIS (Katsanevakis *et al.*, 2014). The outputs of the Systematic Review identified the ability of this NIS to compensate for large changes in temperature and salinity regimes, with wider thermo-tolerance ranges and increased tolerance of higher salinities in comparison to native Mediterranean bivalves (Appendix 1). No evidence exists within the current literature on the effect of trophic status on the presence of *B. pharaonis*, although as most filter feeder diets comprise of fresh particulate organic matter and detritus, *B. pharaonis* will likely be affected by trophic condition shifts as expressed by changes in suspended chlorophyll-a.

Under future scenarios for 2030 and 2050, eight predictors were identified, with chlorophyll-a, salinity and surface temperature exerting the greatest influence on the invasion pathway for *B. pharaonis* (Tables A1-A3; Fig. A2, A3 jackknife test in Appendix 2). Chlorophyll-a (adopted as a proxy of local urbanisation; Nixon 2009), salinity and surface temperature (as a proxy of tropicalisation; Azzurro *et al.,* 2013) were the predictors accounting for the highest percentage of the modelled current distribution (Table A1 and Fig.

A1 jackknife test in Appendix 2), which was in accordance with the values in published literature (AUC = 0.816 ± 0.052; Fig. 2 year 2010 current scenario). For the 2010 model, the marginal response of *B. pharaonis* to the selected environmental variables is reported in Fig. A4 (Appendix 2). Of all stressor predictor variables tested, salinity change will be the most important driver modifying Lessepsian NIS distribution pathways (Rilov & Galil 2009; Nagar *et al.,* 2016; Galil *et al.,* 2017). As is already well-known from the literature (Sarà *et al.,* 2008) this species shows a marked hypersaline affinity and the forecasted increase in salinity will likely promote the spatial spread of the propagules toward the Western basin.

Habitat Suitability

In 2030, the contribution of climate-related factors will increase the forecasted habitat suitability HSI by 47%, 25% and 14% for the Eastern, Central and Western basins respectively (Table 1) in comparison to 2010 (Fig. 2 and Fig. 3). Estimating the HSI likelihood under increasing salinity scenarios arising from the new Suez Canal opening (from +0.1 to +0.5 psu; Table 1) and under no-change trophic conditions (*i.e.* no change; Table 1), in 2030 HSI will increase by 161%, 53% and 27% for the Eastern, Central and Western basins, respectively. Similarly, in 2050 under no change trophic conditions, HSI will increase by 182%, 75% and 40% respectively. If the trophic conditions of the three Mediterranean basins become more eutrophic, the HSI will also dramatically increase (see Table 1 right panels; Figs. 3, 4). Conversely, an overall reduction in HSI values will occur for the whole Mediterranean Sea under conditions of decreased salinity and oligotrophication (of Table 1 left panels; Fig. 3, Fig. 4). The effect of changes in chlorophyll-a concentrations depends on the basin considered. For the scenario with no change in salinity in 2030, eutrophication leads to increase in HSI by 16.30%, while decrease by -2.08% is expected for more oligotrophic conditions in the Eastern basin. Exactly the opposite pattern, however, occurs in the Western basin with a decrease by -2.03% in case of eutrophication and increase of 26.02% for oligotrophication. Similarly, when the salinity is increasing by +0.5 psu, HSI in the Western basin increases more strongly for oligotrophication (+48.84%) than for eutrophication scenario (+27.28%), but the opposite response occurs in the East (+129.15% *vs* +153.69%).

The interactions between HSI and the environmental variables considered in 2010 were reported in Fig. A5 (Appendix 2). The results highlighted that the salinity (0.45) and the SST (0.38) were the most correlated environmental variables with the HSI.

In Figures 5 and 6 are represented the number of scenarios in which the HSI resulted greater than 0.7 for the 2030 and 2050 respectively. The frequency of agreement between models outputs, in both time periods, resulted higher in the Eastern portion of the Mediterranean basin, while the area of the Aegean Sea and the South Eastern Italy presented lowest values. HSI never resulted > 0.7 within the Western Mediterranean basin in the scenarios analysed.

Multiple stressors

In 2030 and 2050 the combined effects of multiple stressors will generate a synergistic effect under increased salinity scenarios. In contrast, the effects of multiple stressors will generate an antagonistic response under decreasing salinity scenarios. In particular, the climate change stressors (SST and wind stress) will increase HSI by 11%, 18% and 8% in 2030 and 32%, 41% and 32% in 2050 for the Eastern, Central and Western basins, respectively (Table 1). A synergistic effect (Table 1) is evident with changes in trophic status conditions (HSI will range from -2% to 26% in 2030 and 19% to 48% in 2050). Under future decreasing salinity scenarios there will be a decrease in the mean HSI (Table 1), whereas HSI will increase under increasing salinity scenarios, with the effect being more marked in 2050.

Potential interactions, representing the response of HSI to pairwise stressor combinations are reported in Appendix 2 (Figs. A4, A5).

Discussion

The forecast scenarios show unexpected consequences when climate change interacts with increasing salinity derived from the new Suez Canal opening, which will be further altered by changing trophic conditions produced by local human pressures (*sensu* Nixon 2009). The main predicted effect of the doubling of the Suez Canal will be the increase of the propagule pressure for a great variety of species that are likely to colonize the Levantine waters. The future spread of the Lessepsian bivalve *B. pharaonis* westwards in the Mediterranean Sea is forecast for both periods 2030 and 2050 under a 10% increase in eutrophication scenario, when both climate change and salinity increase are modelled together, with interaction effects evident. The pathway from the current, localized distribution within the introduced range in the western Mediterranean basin is predicted to predominantly follow a north-westerly trajectory, with colonisation of new sites forecast along the northern coastline. Some colonization of the southern coastline is also predicted, but to a far lesser extent. Secondary introductions (*e.g.* through ballast waters) in a westerly direction from Levantine waters are a more complex phenomenon, potentially related to the warming of the sea and also to additional hydrographic changes that are a consequence of the global climate change (*e.g.* salinity and trophic factors). The interregional differences showed by our modelling are predominantly related to the spatial variation in the productivity across the Mediterranean Sea, with more oligotrophic conditions prevailing in the Eastern sector. Considering the preference of *B. pharaonis* for average levels of productivity, the increase in productivity by 10% should facilitate the spread throughout the Eastern basin, but at the same time hinder the invasion in Western waters that are already eutrophic.

Synergistic interactions cause the equilibrium of native communities to shift, favoring NIS invasions. A climate facilitated expansion will likely result from future increases in temperature, as the spread of *B. pharaonis* will be promoted under conditions of interacting stressors of trophic and salinity changes.

To date, however, there is a lack of biogeochemical models and the availability of projected datasets for salinity and eutrophication is still scant. Thus, the reliability of projected scenarios is widely debated and considered less confident than that of other variables considered in this study (*e.g.* sea surface temperature, wind stress etc.). Following the precautionary principle, a set of sensitivity analysis was performed to cover all possible expected changes.

A number of criticisms have been advanced against the use of SDMs, *e.g.* these tools not consider biotic interactions, evolutionary change and species dispersal (Pearson & Dawson 2003). However, the SDM approach can provide useful first results, giving an approximation of the impact of environmental change including climate on species distribution (Pearson & Dawson 2003; Guisan & Thuiller 2005; Wiens *et al.,* 2009; Guisan *et al.,* 2013). Despite limitations, SDMs may be useful to assist in conservation planning by contributing to strategic decisions about environmental change impacts, and can play a key role by highlighting likely shifts of suitable habitat of NIS invasion (Thuiller *et al.,* 2005; Araujo *et al.,* 2011). One of the main problems of SDMs could be due to the potential underestimation of the potential spread of these species and consequentially the suitable habitat predicted can represent only a conservative estimate (Parravicini *et al.,* 2015).

The use of SDM tools remains challenging, but the potential to assess future invasion risk by identification of areas vulnerable to invasion demonstrates the value of this method for predicting potential NIS distributions.

Future range expansion

Although a degree of uncertainty inherent in all modelling approaches may complicate projections of future biodiversity (Guisan & Thuiller 2005; Thuiller *et al*., 2005; Walther 2007), SDMs represent the best approach to date with which to forecast biological invasions (Walther *et al*., 2011). Our predictions represent an excellent test to evaluate invasive distribution shifts within marine systems using models developed and validated for terrestrial ecosystems (Fernández & Hamilton 2015). When coupled with functional trait-based approaches based on the fundamental niche (Sarà *et al.,* 2013), such results may improve the ability to predict changes from current to future spatial distributions of NIS. The model outputs support hypothesis that the NIS *B. pharaonis* will proliferate from its current invasive distribution to 2050 under future salinity and eutrophication scenarios, being able to colonise hard substrata across the Mediterranean (Fig. 4). This Lessepsian NIS will expand its invasive range by more than 1,000 km in a westerly trajectory with respect to hydrographic conditions, reaching the Spanish coasts and the Gibraltar Strait by 2050. This is consistent with predictions made by Sarà *et al.* (2013) based on mechanistic functional trait based models, which were performed to test the reliability of that approach to predict current physiologically suitable habitats for this species. Although there were no historical records of occurrence further west in the North Atlantic in the literature, the likelihood of *B. pharaonis* being present was also predicted along the African (*e.g.* Libya), Southern Italian Peninsula (*e.g.* Calabria) and Northern Sardinia coasts both during 2030 and 2050 (Fig. 3 and 4; Table 1).

Policy implications of invasion

Our results demonstrate that current European management actions and marine spatial planning frameworks that are based solely on measures to manage ballast waters and hull-fouling as the primary vector of invasion (see Ojaveer *et al*., 2014 for an updated and detailed list) may be rendered ineffective by the construction of manmade corridors such as the new Suez Canal opening. The SDM approach presented here provides a new tool with which to realistically predict habitat suitability for NIS, *via* a worked example for one NIS model species, *B. pharaonis*.

Our invasion maps (Figs. A6 and A7 in Appendix 2) will assist managers to identify areas of vulnerability for native ecosystems. These geospatial model outputs will facilitate the development and implementation of new, effective mitigation actions to prevent novel, favourable conditions for the introduction of NIS, and subsequently address the related risks and cost to policymaking and administration at the national and European levels (Hulme *et al.,* 2008). In addition, these models can be more widely applied to coastal marine systems globally to forecast invasion dynamics for benthic marine species under a range of multiple stressor scenarios.

At the European scale, these quantitative, geo-referenced, spatially-explicit risk maps of biological invasions under changing environmental conditions provide powerful visual communication and decision-support tools with which to describe where and when species might invade, and provide geo-spatial trajectories of future spread. The need to predict the NIS distribution pathways within the context of multiple stressors, including environmental and anthropogenic drivers is a primary and essential step to identify and evaluate management options and decisions to regulate and prevent new introductions. SDMs are useful statistical toolkits with which to geospatially map past, current and future biogeographic ranges for NIS, accommodating multiple stressor scenarios to enable more realistic forecasts of environmental and anthropogenic stressors and the resultant impacts on the range and spread of NIS into new areas.

Risk/pest maps are a valuable tool for the accurate assessment of Good Environmental Status (GES) for member state compliance with the EU Marine Strategy Framework

Directive. GES targets are set against a background of "prevailing physiographic, geographic and climatic conditions" for MSFD Descriptor 1, Biological diversity is maintained, and Descriptor 2, Non-indigenous species (NIS) introduced by human activities are at levels that do not adversely alter the ecosystems (European Union 2008). At the present time, there are no standard methods to calculate the future distribution and status of native and invasive species in European waters with respect to uncontrollable environmental drivers such as climate change, salinity, eutrophication etc. termed "prevailing… conditions" (European Union 2008).

Pest maps will provide additional information on the ecological and economic impacts of invasion, predicting future risks areas, discussing and addressing related costs relevant to policy and management practices. By combining and overlapping our maps with outputs from a mechanistic trait-based approach (*e.g.* Sarà *et al.,* 2013) and human use layers (aquaculture farms; *e.g.* Brigolin *et al.*, 2017; major ports, hubs of international maritime transport; *e.g.* the Milazzo harbour in Sicily; D'Alessandro *et al.,* 2016 and to see Appendix 1 for more references around the Mediterranean basin) or layers of spatial management measures (*e.g.* Marine Protected Areas to see Galil *et al.*, 2017; Special Protection Areas to see the Stagnone di Marsala in Sicily Sarà *et al.*, 1999), we show that locations predicted to be highly suitable for colonization by *B. pharaonis* may overlap with protected or highly anthropic areas that are highly likely to receive new propagules. The same exercise can be done using the major shipping routes within the Mediterranean Sea or using the circulation patterns or more other local maritime use layer.

This approach can be more widely applied to any marine species for which current distributional, ecological and environmental tolerance data are available, and thus has wide potential applications for quantitatively determining the changes in GES with respect to the relative contributions of a range of drivers, including uncontrollable environmental change and local/regional anthropogenic stressors. Interestingly, this species shares similar distribution patterns with other marine invasive species whose biogeographic ranges are driven by temperature (*e.g.* the European green crab, *Carcinus maenas*; Compton *et al.,* 2010; and other benthic invertebrate; de Rivera *et al.,* 2011) and specifically with other Lessepsian invaders clearly showing climatic niche expansion in the Mediterranean (Azzurro *et al.,* 2013; Weinmann *et al.*, 2013; Parravicini *et al.,* 2015). Given the vastly different ecology of these species (fish, large benthic foraminifera and mussels) the consistency of the obtained results might represent a major step in making broader generalizations about the future spread of Lessepsian species under changing climate conditions. More specifically, combination of both chlorophyll-a and salinity were the most influential environmental variables explaining the expansion or abiotic resistance to this the invasion of the bluespotted cornetfish *Fistularia commersonii* (Osteichtyes, Fistulariidae; Azzurro *et al.,* 2013). Both for fish and large foraminifera the main future areas of environmental suitability were identified along the northern coasts of the Levantine Sea, Egypt, Turkey Dodecanese, Sicily Strait and Tyrrhenian Sea, with suitability continuously increasing towards the Central and Western Mediterranean Sea along the coasts of Italy, Croatia, Montenegro and Albania in the Adriatic Sea, in Sicily and along the western coast of Italy (Azzurro *et al.,* 2013; Weinmann *et al.,* 2013).

An additional finding of the literature assessment suggests that *in situ* monitoring is the most effective option to support biological invasion management, via the provision of early detection warnings, and a rapid response derived from field data. Active and ongoing NIS monitoring programs should be continued to track new introductions and spread of NIS, evaluate changes in species composition and assess the status of both vulnerable and resilient ecosystems (Butchart *et al.,* 2010). Prevention seems to be the only feasible management alternative when facing the need to take post-invasion adaptive management actions to control biological invasions in marine ecosystems. Information on future invasion spread combined with data of propagule pressure, and the roles that climatic and anthropogenic drivers play in altering invasion dynamics will be crucial in informing prevention and monitoring strategies suggesting where to focus monitoring plans and target management options at appropriate scales and frequencies (from local to regional) to successfully mitigate invasions and minimize their impact on native biodiversity, ecosystem services and human activities (McDonald-Madden *et al*., 2011; Norton *et al*., 2015; Marzloff *et al.,* 2016; Pecl *et al.,* 2017).

Using data collected from observational and experimental research on multiple stressors, and target species as input variables ensures scientific rigor of the SDM outputs encourages a “call for collection of …” species occurrence and environmental data, at both finer scales and in additional spatial regions. Such research-based, integrated approaches are a priority over the coming decades as climate-facilitated biological invasions will create new and unexpected challenges for biodiversity conservation.

Acknowledgements

PRIN TETRIS 2010 grant n. 2010PBMAXP_003, funded by the Italian Minister of Research and University (MIUR) supported this research. NM was funded by a Marine Biological Association of the UK Research Fellowship and the University of Liverpool. The authors declare no competing financial interests.

References

Adloff F, Somot S, Sevault F *et al*. (2015) Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios. Climate Dynamics, **4,** 2775-2802. DOI 10.1007/s00382-015-2507-3.

Araujo MB, Alagador D, Cabeza M, Nogues-Bravo D, Thuiller W (2011). Climate change threatens European conservation areas. Ecology Letters, 14, 484–492.

Azzurro E, Soto S, Garofalo G, Maynou F (2013) *Fistularia commersonii* in the Mediterranean Sea: invasion history and distribution modeling based on presence-only records. Biological Invasions, **15**(5), 977-990.

Bilotta GS, Milner AM, Boyd, I (2014) On the use of systematic reviews to inform environmental policies. Environmental Science and Policy, **42**, 67–77.

Bonnici L, Evans J, Borg JA, Schembri PJ (2012) Biological aspects and ecological effects of a bed of the invasive non-indigenous mussel *Brachidontes pharaonis* (Fischer P., 1870) in Malta. Mediterranean Marine Science **13**(1):153-161.

Boudouresque C (2004) Marine biodiversity in the Mediterranean: status of species, populations and communities. Scientific Reports of the Port-Cros National Park, **20**, 97-146.

Bradley BA, Blumenthal DM, Wilcove DS, Ziska LH (2010) Predicting plant invasion in an era of global change. Trends in Ecology and Evolution, **25**, 310-318.

Brigolin D, Porporato EMD, Prioli G, Pastres R (2017) Making space for shellfish farming along the Adriatic coast. ICES Journal of Marine Science, **74**(6), 1540-1551.

Burrows MT, Schoeman DS, Richardson AJ *et al*. (2014) Geographical limits to species-range shifts are suggested by climate velocity. Nature, **507**, 492-495.

Butchart SHM, Walpole M, Collen B *et al*. (2010) Global biodiversity: indicators of recent declines. Science, **328**, 1164-1168.

Chapman DS, Makra L, Albertini R *et al*. (2016) Modelling the introduction and spread of non-native species: International trade and climate change drive ragweed invasion. Global Change Biology DOI: 10.1111/gcb.13220.

Collaboration for Environmental Evidence (CEE) (2013) Guidelines for systematic review and evidence synthesis in environmental management. 2013. Version 4.2. Environmental Evidence: [http://environmentalevidence.org/Documents/Guidelines/Guidelines4.2.pdf]

Compton TJ, Leathwick JR, Inglis GJ (2010) Thermogeography predicts the potential global range of the invasive European green crab (*Carcinus maenas*). Diversity and Distributions, **16**(2), 243-255.

D'Alessandro M, Esposito V, Giacobbe S, Renzi M, Mangano MC, Vivona P, Consoli P, Scotti G, Andaloro F, Romeo T (2016) Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of biological, physical and chemical indicators. Marine Pollution Bulletin, **106**(1), 260-273.

Delong ER, Delong DM, Clarke-Pearson DL (1988) Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics, **44**, 837-845.

Dormann CF, McPherson JM, Araújo MB, Bivand R, Bolliger J *et al.* (2007) Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. Ecography, **30**, 609-628.

de Rivera CE, Steves BP, Fofonoff PW, Hines AH, Ruiz GM (2011) Potential for high‐latitude marine invasions along western North America. Diversity and Distributions, **17**(6), 1198-1209.

Elith J, Graham CH, Anderson RP, Dudik M, Ferrier S, Guisan A *et al.* (2006) Novel methods improve prediction of species distributions from occurrence data. Ecography, 29, 129-151.

Elith J, Leathwick JR (2009) Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. Annual Reviews in Ecology and Evolutionary Systems, **40,** 677-697.

European Union (2008) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European Union **L 164/19** pp. 22.

Feld CK, Segurado P, Gutiérrez-Cánovas C (2016) Analysing the impact of multiple stressors in aquatic biomonitoring data: A ‘cookbook’ with applications in R. Science of the Total Environment, **573**, 1320-1339.

Fernández M, Hamilton H (2015) Ecological Niche Transferability Using Invasive Species as a Case Study. PLoS ONE, **10,** e0119891.

Floerl O, Rickard G, Inglis G, Roulston H (2013) Predicted effects of climate change on potential sources of non indigenous marine species. Diversity and Distributions, **19,** 257-267.

Galil BS (2009) Taking stock: inventory of alien species in the Mediterranean sea. Biological Invasions **11,** 359-372.

Galil BS, Boero F, Campbell ML *et al.* (2015) ‘Double trouble’: the expansion of the Suez Canal and marine bioinvasions in the Mediterranean Sea. Biological Invasions, **17,** 973-976.

602 Galil B, Marchini A, Occhipinti-Ambrogi A, Ojaveer H (2017) The enlargement of the Suez Canal-Erythraean introductions and management challenges. Management of Biological Invasions **8**.

605 Gallien L, Münkemüller T, Albert CH, Boulangeat I., Thuiller W (2010) Predicting potential distributions of invasive species: where to go from here? Diversity and Distributions, **16,** 331-342.

608 Gurevitch J, Hedges LV (2001) Meta-analysis: Combining the Results of Independent experiments. In: Design and analysis of ecological experiments (eds Scheiner, SM and Gurevitch, J), pp. 347-369. Oxford University Press, Oxford, United Kingdom.

611 Guisan A, *et al.* (2013) Predicting species distributions for conservation decisions. Ecology Letters, 16, 1424-1435.

613 Guisan A, Thuiller W (2005) Predicting species distribution: offering more than simple habitat models. Ecological Letters*,* **8**, 993-1009.

615 Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. Ecological Modelling*,* **135**, 147-186.

617 Hamaoui-Laguel L, Vautard R, Liu L *et al*. (2015) Effects of climate change and seed dispersal on airborne ragweed pollen loads in Europe. Nature Climate Change **5**, 766-771.

620 Helmuth B, Mieszkowska N, Moore P, Hawkins SJ (2006) Living on the edge of two changing worlds: forecasting the impacts of climate change on rocky intertidal ecosystems. Annual Review of Ecology Systematics and Evolution **37**, 373-404.

623 Hosmer DW, Lemeshow S (1989) Applied logistic regression. Wiley, New York.

624 Hulme PE, Bacher S, Kenis M *et al*. (2008) Grasping at the routes of biological invasions: a framework for integrating pathways into policy. Journal of Applied Ecology*,* **45.2**, 403-313.

Hulme PE (2009) Trade, transport and trouble: managing invasive species pathways in an era of globalization. Journal of Applied Ecology, **46**, 10-1.

Katsanevakis S, Zenetos A, Belchior C, Cardoso AC (2014) Invading European Seas: assessing pathways of introduction of marine aliens. Ocean and Coastal Management, **76**, 64-74.

Lenz M, da Gama BA, Gerner NV *et al*. (2011) Non-native marine invertebrates are more tolerant towards environmental stress than taxonomically related native species: results from a globally replicated study. Environmental Research, **111**(7), 943-952.

Lima FP, Ribeiro PA, Queiroz N, Hawkins SJ, Santos AM (2007) Do distributional shifts of northern and southern species of algae match the warming pattern? Global Change Biology, 13(12), 2592-2604.

Mangano MC, Sarà G (2017a) Collating science-based evidence to inform public opinion on the environmental effects of marine drilling platforms in the Mediterranean Sea. Journal of Environmental Management, **188**, pp.195-202.

Mangano MC Sarà G (2017b) The author's reply to NR Haddaway. Journal of Environmental Management, **197**, pp.114-116.

Mangano MC, Sarà G, Corsolini S (2017) Monitoring of persistent organic pollutants in the polar regions: knowledge gaps & gluts through evidence mapping. Chemosphere, **172**, pp.37-45.

Marzloff MP, Melbourne-Thomas J, Hamon KG, Hoshino E, Jennings S, Putten IE, Pecl GT (2016) Modelling marine community responses to climate-driven species redistribution to guide monitoring and adaptive ecosystem-based management. Global Change Biology, **22**(7): 2462-2474.

McDonald-Madden E, Runge MC, Possingham HP, Martin TG (2011) Optimal timing for managed relocation of species faced with climate change. Nature Climate Change, **1**(5), 261-265.

Mieszkowska N, Kendall MA, Hawkins SJ, Leaper,R, Williamson P, Hardman-Mountford NJ Southward AJ (2006) Changes in the range of some common rocky shore species in Britain - a response to climate change? Hydrobiologia, **55,** 241-251.

Mieszkowska N, Sugden H, Firth L & Hawkins SJ (2014) The role of sustained observations in tracking impacts of environmental change on marine biodiversity and ecosystems. Philosophical Transactions of the Royal Society A, **372.2025**, 20130339 http://dx.doi.org/10.1098/rsta.2013.0339

Nagar LR, Shenkar N (2016) Temperature and salinity sensitivity of the invasive ascidian *Microcosmus exasperatus* Heller, 1878. Aquatic Invasions, **11**(1), 33-43.

Naimi B (2013) usdm: Uncertainty analysis for species distribution models. R package version 1.1-12. http://CRAN.R-project.org/package.

Nenzén HK & Araújo MB (2011) Choice of threshold alters projections of species range shifts under climate change. Ecological Modelling, **222**(18), 3346-3354.

Nixon S (2009) Eutrophication and the macroscope. Hydrobiologia, **629**, 5-19.

Norton DA, Warburton B (2015) The potential for biodiversity offsetting to fund effective invasive species control. Conservation Biology, **29.1**, 5-11.

Ojaveer H, Galis BS, Minchin D *et al*. (2014) Ten recommendations for advancing the assessment and management of non-indigenous species in marine ecosystems. Marine Policy, **44**, 160-165.

Pachauri RK, Allen MR, Barros VR *et al*. (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change (eds.R. Pachauri, L. Meyer) IPCC, pp. 151, ISBN: 978-92-9169-143-2, Geneva, Switzerland.

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature*,* **421**, 37-42.

Parravicini V, Azzurro E, Kulbicki M, Belmaker J (2015) Niche shift can impair the ability to predict invasion risk in the marine realm: an illustration using Mediterranean fish invaders. Ecology Letters, 18, 246-253.

Pearson RG, Dawson TP (2003) Predicting the impacts of climate change on the distribution of species: are bioclimatic envelope models useful? Global Ecology and Biogeography **12**, 361-371.

Pederson J, Mieszkowska N, Carlton JT, Gollasch S, Jelmert A, Minchin D, Occhipinti-Ambrogi A, Wallentinus I (2011) ICES Position Paper on Climate Change Chapter 11: Climate Change and Non-Native Species in the North Atlantic. In: CES Status Report on Climate Change in the North Atlantic (eds. Reid, PC, Valdés L), 174-190.

Payne MR, Barange M, Cheung WW *et al.* (2015) Uncertainties in projecting climate change impacts in marine ecosystems ICES Journal of Marine Science: Journal du Conseil, fsv231.

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. Ecological Modelling*,* **190**, 231-259.

Phillips SJ. Dudík M (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography, **31**, 161-175.

Pecl GT, Araujo MB, Bell J, Blanchard J, Bonebrake TC, Chen I, Clark TD, Colwell RK, Danielsen F, Evengard B, Robinson S *et al.,* (2017) Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. Science **35**(6332): 1-9.

Poloczanska ES, Brown CJ, Sydeman WJ *et al*. (2013) Global imprint of climate change on marine life. Nature Climate Change, **3**(10), 919-925.

Richter R Dullinger S, Essl F, Leitner M, Vogl G (2013) How to account for habitat suitability in weed management programmes? Biological Invasions, **15**, 657-669.

Rilov G, Galil B (2009) Marine bioinvasions in the Mediterranean Sea – History, distribution and ecology. In Biological Invasions in Marine Ecosystems (Rilov, G. & Crooks, J. A., eds.), pp. 549-575. Berlin Heidelberg: Springer.

Ruiz GM, Ruiz GM, Fofonoff PW, Carlton JT, Wonham MJ, Hines AH (2000) Invasion of Coastal Marine Communities in North America: Apparent Patterns, Processes, and Biases. Annual Reviews in Ecology and Evolutionary Systems, **31**, 481-531.

Safriel UN, Gilboa A, Felsenburg T (1980) Distribution of Rocky Intertidal Mussels in the Red Sea Coasts of Sinai, the Suez Canal and the Mediterranean Coast of Israel, with Special Reference to Recent Colonizers. Journal of Biogeography **7**(1): 39-62.

Safriel UN, Sasson-Frostig Z (1988) Can colonizing mussel outcompete indigenous mussel? Journal of Experimental Marine Biology and Ecology **117**(3): 221-226.

Sarà G, Romano C, Widdows J, Staff FJ (2008) Effect of salinity and temperature on feeding physiology and scope for growth of an invasive species (*Brachidontes pharaonis* - Mollusca: Bivalvia) within the Mediterranean Sea. Journal of Experimental Marine Biology and Ecology, **363**: 130-136.

Sarà G, Leonardi M, Mazzola A (1999) Spatial and temporal changes of suspended matter in relation to wind and vegetation cover in a Mediterranean shallow coastal environment. Chemistry and Ecology, **16**(2-3), pp.151-173.

Sarà G, Palmeri V, Rinaldi A, Montalto V, Helmuth B (2013) Predicting biological invasions in marine habitats through eco-physiological mechanistic models: a case study with the bivalve *Brachidontes pharaonis*. Diversity and Distributions, **19**, 1235-1247.

Sorte CJ, Williams SL, Carlton JT (2010) Marine range shifts and species introductions: comparative spread rates and community impacts. Global Ecology and Biogeography, **19(3)**, 303-316.

Thuiller W, Richardson DM, Pyšek P, Midgley GF, Hughes GO, Rouget M (2005) Niche based modelling as a tool for predicting the risk of alien plant invasions at a global scale. Global Change Biology, **11(12)**, 2234-50.

Verbruggen H (2012) OccurrenceThinner 1:04. http://www.phycoweb.net/software/OccurrenceThinner/. Accessed: 2016 May.

Verbruggen H, Tyberghein L, Belton GS, Mineur F, Jueterbock A, Hoarau G, De Clerck O (2013) Improving transferability of introduced species' distribution models: new tools to forecast the spread of a highly invasive seaweed. PLoS ONE, **8**(6), e68337. doi:10.1371/journal.pone.0068337

Vilà M, Espinar JL, Hejda M, Hulme PE, Jarošík V, Maron JL, Pergl J, Schaffner U, Sun Y, Pyšek P (2011) Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters, **14**, 702-708.

Walther GR (2007) ECOLOGY: Tackling Ecological Complexity in. Science, **315**, 606.

Walther GR, Roques A, Hulme PE *et al*. (2009) Alien species in a warmer world: risks and opportunities, Trends in Ecology and Evolution, **24**, 686–693.

Weinmann AE, Rödder D, Lötters S, Langer MR (2013) Traveling through time: the past, present and future biogeographic range of the invasive foraminifera Amphistegina spp. in the Mediterranean Sea. Marine Micropaleontology, **105**, 30-39.

Wiens JA, Stralberg D, Jongsomjit D, Howell CA, Snyder MA (2009) Niches, models, and climate change: assessing the assumptions and uncertainties. Proceedings of the National Academy of Sciences of the United States of America; **106**(2), 19729-19736.

Zerebecki RA & Sorte CJ (2011) Temperature tolerance and stress proteins as mechanisms of invasive species success. *PLoS One*, **6(4)**, e14806.

Supporting Information may be found in the online version of this article:

Appendix 1 Systematic review outcomes dataset

Appendix 2 Tables detailing variables used, ROC curves and spatial distributions in 2030 and 2050 for all 33 scenarios considered in the Species Distribution Model.

Data Accessibility: Rasters derived from the habitat suitability models will be available as raster grids from the Pangaea database.

Biosketch: Gianluca Sarà (Ph.D., 1994) is Professor of Ecology at University of Palermo (Italy) and coordinates the Laboratory of Experimental Ecology of the Department of Earth and Marine Science. He graduated for his PhD in 1994 at University of Messina (Italy) discussing a thesis dealing with bioenergetics and growth performance of cultivated bivalves in the Southern Mediterranean Sea. Through over 110 peer-reviewed papers published in the last 20 years, his research focuses on the effect of anthropogenic influence on ecosystems and the study of structures and ecosystem functioning through its influence on the rates of synthesis of biological structures, chemical compositions, energy and material fluxes, population processes, species interactions and thereby biodiversity.

Editor: Richard Pearson

Author contributions: G.S. conceived the idea and addressed the objective of analyses, and with N.M. equally led the writing, provided funds, hardware and software facilities; E.M.D.P. carried out the predictive modelling and led the modelling writing; M.C.M. performed the systematic review, led the review and the management issues writing and with other authors equally contributed to draft this manuscript.

Table 1. Percentage of variation of mean Habitat Suitability Index (HSI), in comparison to 2010, within the three considered Mediterranean basins (Eastern, Central and Western) for each of the 66 simulated scenarios, respectively for 2030 and 2050 under different trophic and salinity scenario (OLIGOTROPHIC = OLIGOTROPHICATION; EUTROPHIC = EUTROPHICATION).

		DECREASE					2030	INCREASE				
		SALINITY										
		0.5	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.5
OLIGOTROPHIC	Eastern	-26.44	-17.48	-18.12	-13.26	-10.05	-2.08	44.43	68.73	135.26	129.59	129.15
	Central	-6.62	5.16	2.65	10.57	14.05	14.73	17.11	20.53	30.87	42.80	106.07
	Western	1.92	13.24	12.00	18.35	23.77	26.02	27.99	27.02	35.33	48.31	48.84
NO CHANGE	Eastern	-12.66	-13.19	-8.03	-1.26	0.66	10.91	61.73	116.12	116.84	122.62	139.13
	Central	0.36	0.47	1.21	12.45	11.77	18.23	19.92	29.67	30.00	45.71	111.71
	Western	-1.87	-5.21	-2.28	6.47	5.58	7.74	13.56	20.51	19.74	26.71	36.08
EUTROPHIC	Eastern	-8.96	1.49	0.65	-0.87	3.94	16.30	67.72	107.24	145.66	147.54	153.69
	Central	-2.73	6.46	5.80	6.82	6.51	15.91	21.49	32.32	27.63	48.51	115.16
	Western	-16.47	-9.35	-7.65	-6.33	-8.67	-2.03	6.55	19.68	7.60	19.99	27.28

		DECREASE					2050	INCREASE				
		SALINITY										
		0.5	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.5
OLIGOTROPHIC	Eastern	-1.58	3.09	5.57	8.54	11.46	18.88	74.91	113.07	154.10	160.10	181.08
	Central	20.74	22.98	25.91	30.05	37.90	41.39	43.21	48.61	62.12	70.00	134.15
	Western	25.14	25.96	35.27	30.34	41.31	48.01	49.60	51.49	61.96	64.04	67.59
NO CHANGE	Eastern	7.99	15.40	18.36	24.32	27.76	31.83	90.10	137.55	136.39	167.72	185.92
	Central	18.98	25.07	32.71	37.33	34.94	40.69	55.54	58.17	61.25	68.12	136.67
	Western	7.53	11.77	21.91	24.60	21.39	31.63	41.01	37.26	39.76	34.83	53.24
EUTROPHIC	Eastern	19.12	23.41	35.41	31.29	32.80	44.61	94.62	133.33	150.93	177.08	192.60
	Central	24.29	27.82	40.95	35.45	38.31	46.81	48.83	52.88	66.50	74.81	136.41
	Western	0.38	7.34	17.64	15.86	17.04	22.11	22.22	27.05	33.71	34.21	35.32

Figure 1. Temporal trend of the number of scientific publications across the three considered Mediterranean basin (total number of plotted hits 98 except global and regional reviews; search performed at 20/07/2015). Presence records of *B. pharaonis* extracted from literature and employed to run Maxent models (yellow points on the map). The main evolutions of the Suez Canal are reported (yellow labels on the graph, data derived from "http://www.suezcanal.gov.eg/" \t "_blank").

Figure 2. Spatial distributions of predicting suitable habitat of *B. pharaonis* under 2010 current scenario (AUC = 0.809 ±0.043).

Figure 3. Spatial distributions of predicting suitable habitat of *B. pharaonis* under 2030 future scenario, considering the scenarios with a decrease (-0.5 psu, panels a and b) and increase (+0.5 psu panels c and d) of salinity, and both oligotrophication (-10%; on the left, panels a and c) and eutrophication (+10%; on the right, panels b and d) conditions.

Figure 4. Spatial distributions of predicting suitable habitat of *B. pharaonis* under 2050 future scenario, considering the scenarios with a decrease (-0.5 psu, panels a and b) and increase (+0.5 psu panels c and d) of salinity, and both oligotrophication (-10%; on the left, panels a and c) and eutrophication (+10%; on the right, panels b and d) conditions.

Figure 5. Spatial distributions of frequency of predicted Habitat Suitability of *B. pharaonis* under 2030 for all the 33 scenarios.

Figure 6. Spatial distributions of frequency of predicted Habitat Suitability of *B. pharaonis* under 2050 for all the 33 scenarios.

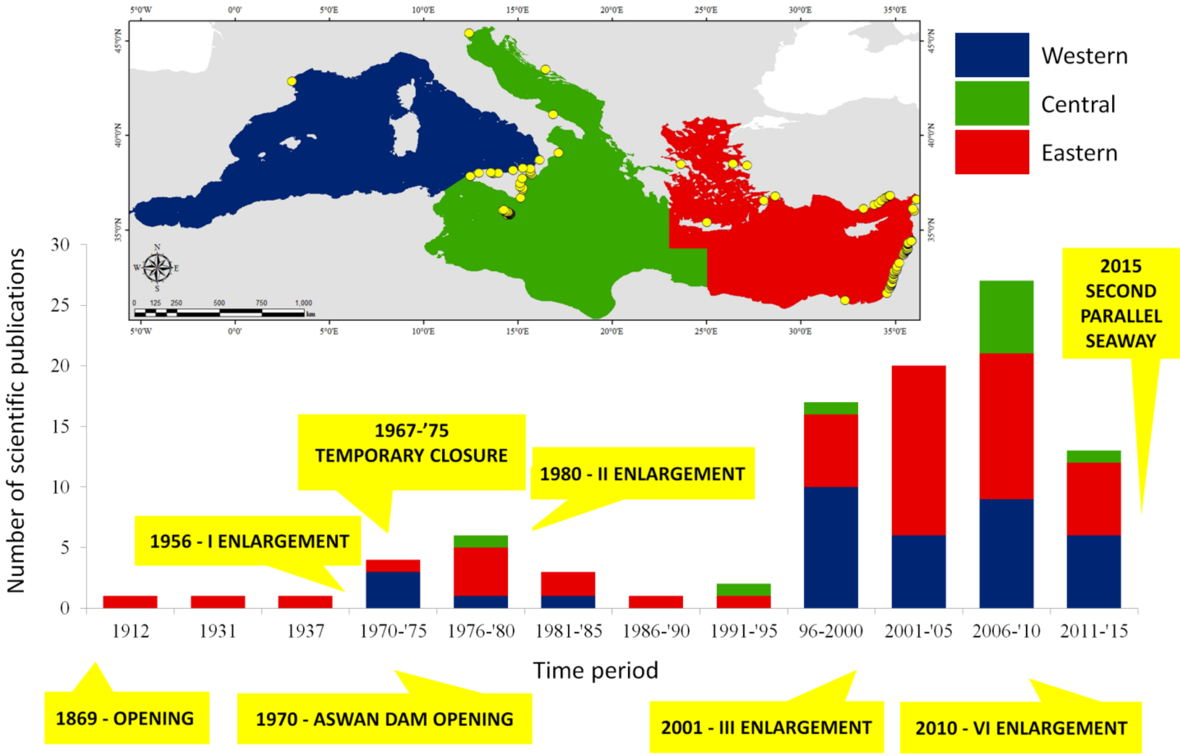

Western
Central
Eastern
Number of scientific publications
0
5
10
15
20
25
30
1912
1931
1937
1970-'75
1976-'80
1981-'85
1986-'90
1991-'95
96-2000
2001-'05
2006-'10
2011-'15
Time period
1869 - OPENING
1956 - I ENLARGEMENT
1967-'75
TEMPORARY CLOSURE
1970 - ASWAN DAM OPENING
1980 - II ENLARGEMENT
2001 - III ENLARGEMENT
2010 - VI ENLARGEMENT
2015
SECOND
PARALLEL
SEAWAY

Figure 1

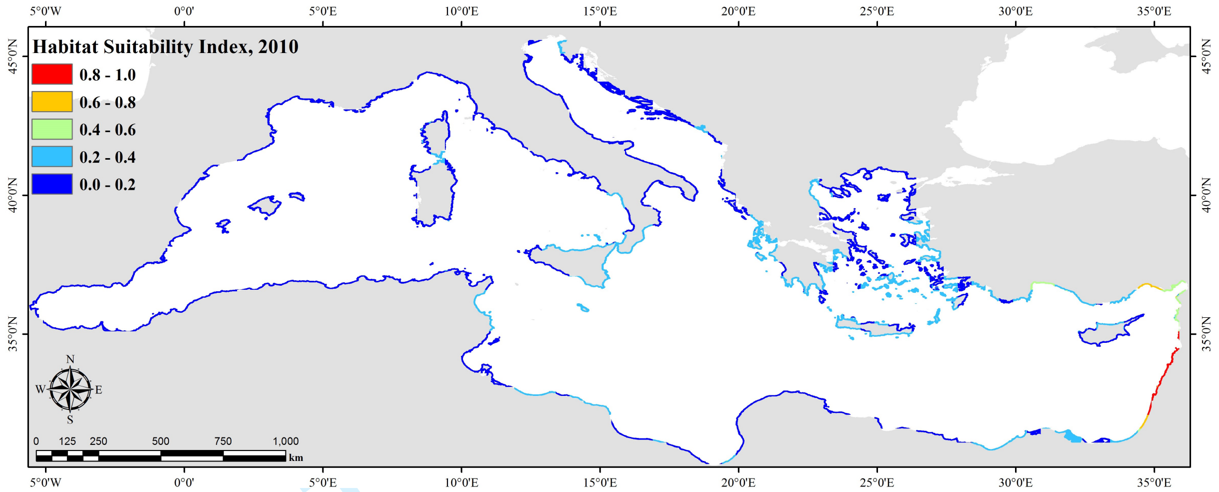

Habitat Suitability Index, 2010
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
N
W
E
S
0 125 250 500 750 1,000
km
5°0'W
0°0'
5°0'E
10°0'E
15°0'E
20°0'E
25°0'E
30°0'E
35°0'E
45°0'N
40°0'N
35°0'N

Figure 2

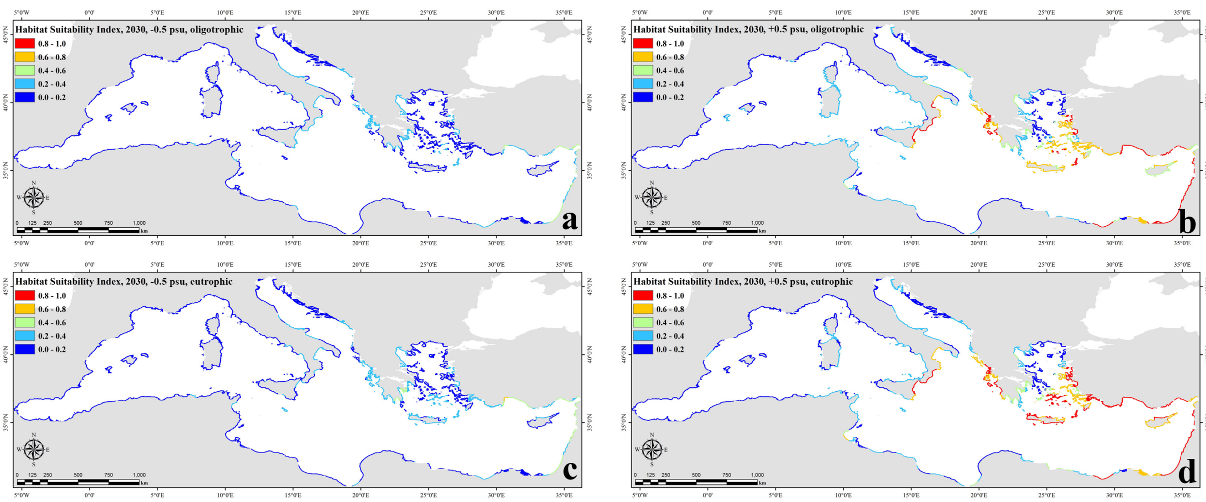

Habitat Suitability Index, 2030, -0.5 psu, oligotrophic
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
a
Habitat Suitability Index, 2030, +0.5 psu, oligotrophic
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
b
Habitat Suitability Index, 2030, -0.5 psu, eutrophic
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
c
Habitat Suitability Index, 2030, +0.5 psu, eutrophic
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
d

Figure 3

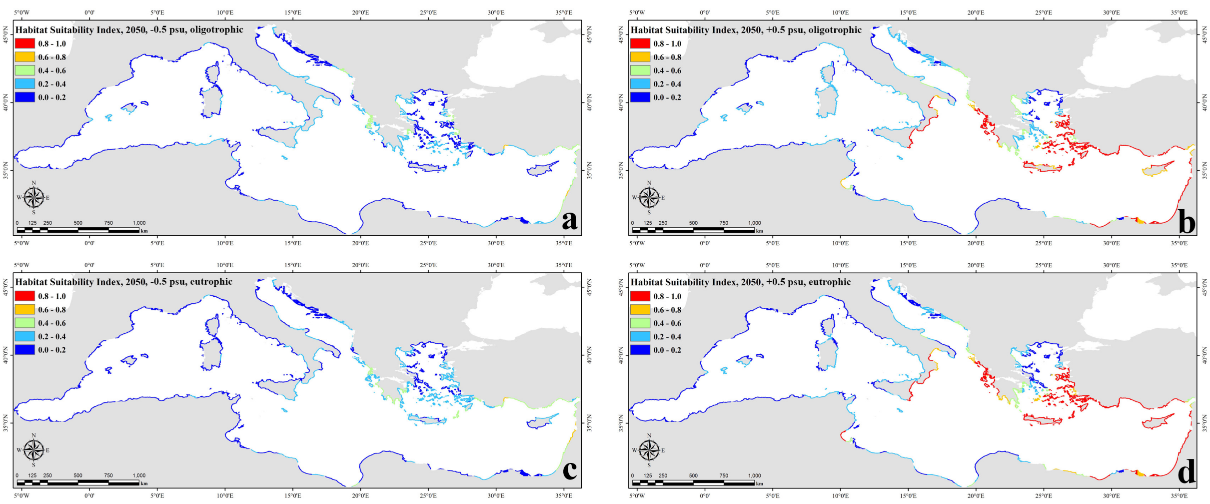
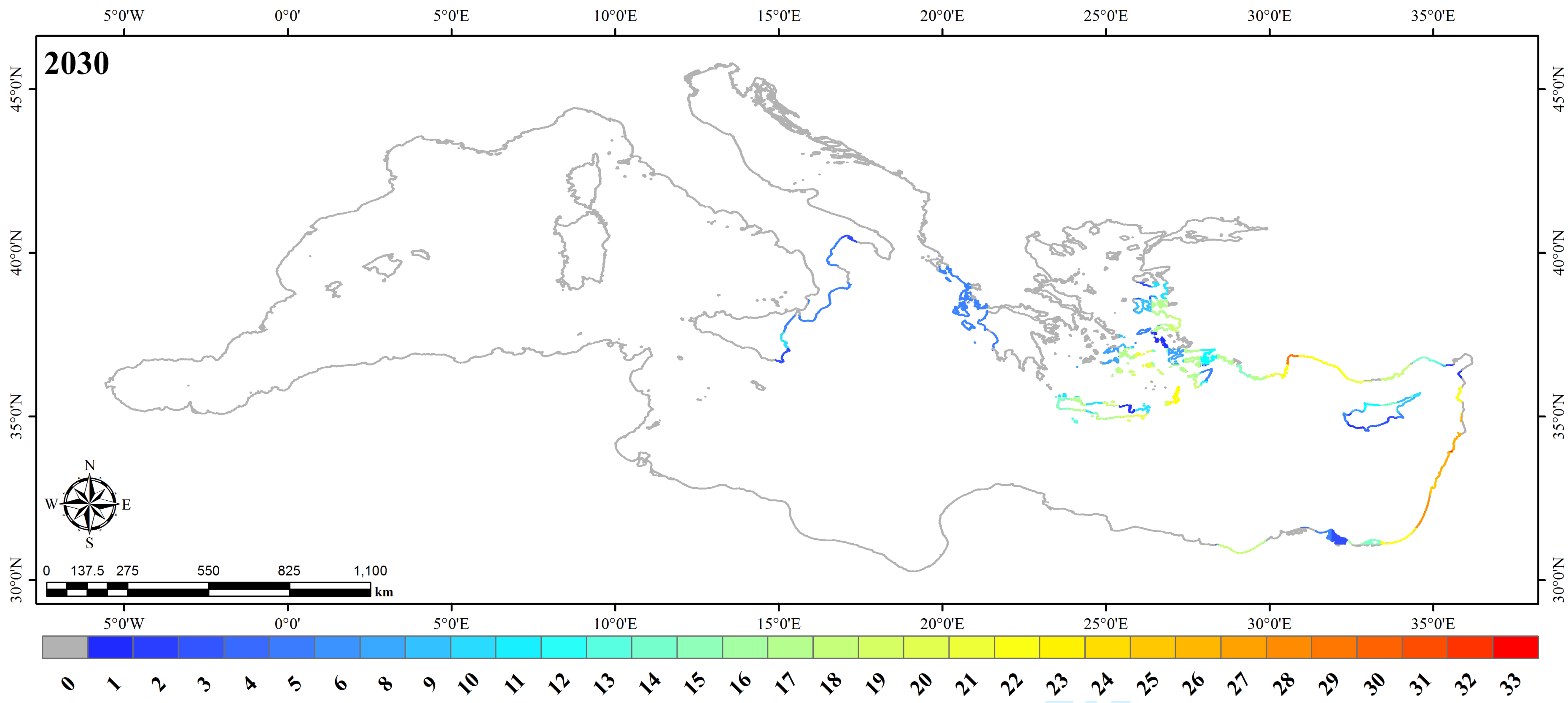

Habitat Suitability Index, 2050, -0.5 psu, oligotrophic
Habitat Suitability Index, 2050, +0.5 psu, oligotrophic
Habitat Suitability Index, 2050, -0.5 psu, eutrophic
Habitat Suitability Index, 2050, +0.5 psu, eutrophic
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
a
b
c
d

Figure 4

19



20 Figure 5

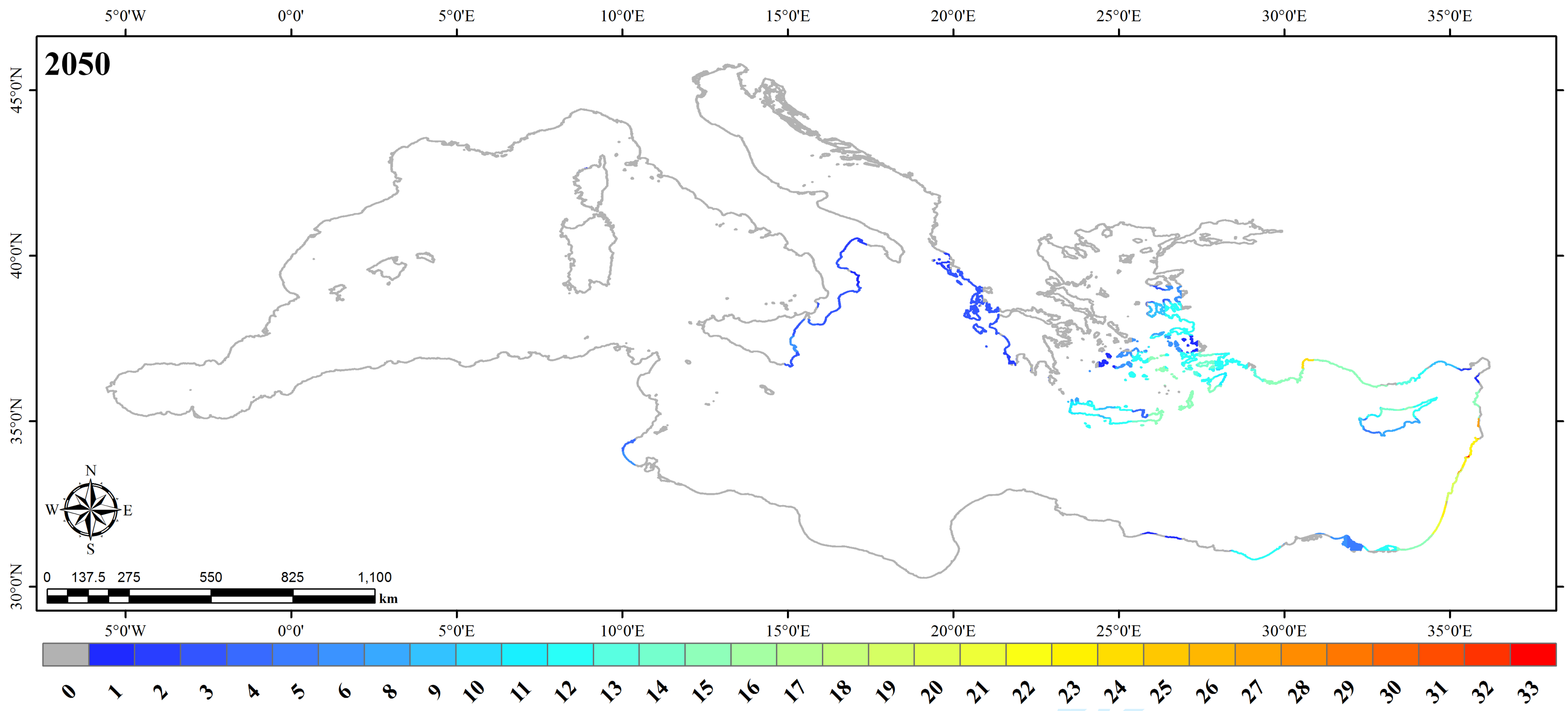

2050
5°0'W
0°0'
5°0'E
10°0'E
15°0'E
20°0'E
25°0'E
30°0'E
35°0'E
45°0'N
40°0'N
35°0'N
30°0'N
N
S
W
E
0 137.5 275 550 825 1,100
km
0 1 2 3 4 5 6 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33

Figure 6

APPENDIX 1, SYSTEMATIC REVIEW OUTCOMES DATASET (search ended at 21/08/2015)

Ref Code	Species	Basin	Country	Locality	Study aims	Habitat	Associated species - assemblages	Density (Ind./m^2)	Min / Max length (mm)	mea n T (°C)	mean Salinity (‰)	mean CHL-a (µg/l)
Bp_1	*B. variabilis*	E	Lebanon	Itanieh, Jiyeh, Beirut, Byblos, Batroun, Tripoli, and Arida	Bioindicators measures of trace metals (Pb, Cd, and V)	-	-	-	-	-	-	-
Bp_2	*B. pharaonis*	E	Turkey	Mersin Bay	Epibiosis study	Calcareous rocks	*Aspidosiphon (Aspidosiphon) elegans*	-	-	-	-	-
Bp_3	*B. variabilis*	W	Italy	Sicily (Augusta)	Biometric study	Calcareous rocks	-	Beds	-	-	-	-
				Sicily (Catania)		Volcanic rocks	-	Patches	7.1 / 14.9	-	-	-
				Sicily (Riposto)		Calcareous rocks	-	-	-	-	-	-
				Sicily (Siracusa)		Calcareous rocks	-	-	-	-	-	-
				Sicily (Milazzo)		-	-	-	-	-	-	-
Bp_4	*B. pharaonis*	C	Italy	Sicily (Stagnone di Marsala)	Measures of temperature dependent-responses (mesocosm)	Rocks at waterline	-	-	-	-	-	-
Bp_5	*B. pharaonis*	E	Palestine	-	Checklist	-	-	-	-	-	-	-
Bp_6	*B. pharaonis*	E	Syria	Ras El Bassit	Checklist	Rocks at waterline	-	100-200	-	20	38.5	-
Bp_7	*B. pharaonis*	E	Lebanon	-	Checklist	-	-		-	-	-	-
Bp_8	*B. pharaonis*	C	Malta	Birzebbugia Bay (Marsaxlokk Harbour)	Effects of mussel bed establishment on the associated biota	Globigerina limestone bedrock	*Bittium* spp., Tanaidae sp., *Rissoa* sp., *Hyale* sp., *Elasmopus* sp., *Dynamene* sp., *Acanthochitona* sp.,	beds - small clusters mixed to marco-	0-5 / 20-30	-		-

							Osilinus turbinatus, *Nereis ?rava*, *Amphitoe* sp.	algae (16550 ± 2051)				
Bp_9	*B. pharaonis*	E	Israel	Tel Aviv (Shemen)	Cellular and molecular responses	Intertidal rocky shore	*Patella cerulea*	-	-	20	38.5	-
				Tel Aviv (Akko)				-	-			-
Bp_10	*B. pharaonis*	W	Italy	Corsica	Checklist	-	-	-	-	-	-	-
Bp_11	*B. pharaonis*	E	Turkey	-	Checklist	-	-	-	-	-	-	-
Bp_12	*B. pharaonis*	E	Greece	Cyprus	Checklist	-	-	-	-	-	-	-
Bp_13	*B. pharaonis*	W	France	Salses-Leucate Lagoon	Food web isotopic characterisation	-	-	Isolated	-	-	-	-
Bp_14	*B. pharaonis*	W	France	Salses-Leucate Lagoon	Food web isotopic characterisation	-	*Zostera noltii* - *Chaetomorpha* sp. - *Ulva* sp. - *Enteromorpha* sp. - *Gammarus aequicauda* - *Idotea* sp.	-	-	-	32	2
Bp_15	*B. pharaonis*	C	Italy	Sicily (Trapani, Saline Ettore-Infersa)	Filter feeding rate	Rocks at waterline	*Cerastoderma glaucum* - *Abra segmentatus* - *Loripes lacteus*	Patches	-	21.3 ± 8	46.8 ± 5.6	-
				Sicily (Stagnone di Marsala)					-	19 ± 6.2	39.2 ± 3.6	-
Bp_16	*B. pharaonis*	E	Greece	-	Checklist	-	-	-	-	-	-	-
Bp_17	*B. pharaonis*	E	Turkey	Iskenderun Bay	New record	Intertidal arificial hard subsyratum	Other bivalves	-	-	25	38.5	-

Bp_18	*B. pharaonis*	C	Malta	Miger Ilma, below Dingli Cliffs	Checklist and mapping	Rocks at waterline	-	-	-	-	-	-
				Marsaskala Bay		Detritus from -4 m	-	-	-	-	-	-
				Bahar iċ-Ċaghaq		Juveniles from tidepool	-	-	-	-	-	-
				Quajjenza, Marsaxlokk Bay		Fish farm nets	-	-	-	-	-	-
				Rinella Bay		Old tyre near shore	-	-	-	-	-	-
				Dwejra, Gozo		Weathered/eroded concrete platform	-	Isolated	-	-	-	-
				Qbajjar Bay, Marsalforn,Gozo		Lower and Middle Globigerina Limestone	-	~10	-	-	-	-
				Blue Lagoon, Comino		Upper Globigerina Limestone coastline	-	Isolated	-	-	-	-
				Ghadira, Mellieha		Upper Coralline Limestone	-	Isolated	-	-	-	-
				Bahar ic-Caghaq–Salini		Upper Globigerina Limestone coastline	-	Isolated	-	-	-	-
							-	~10	-	-	-	-
							-	~100	-	-	-	-
				St George's Bay area, St Julian's		Artificially modified Lower Coralline Limestone coastline	-	Isolated	-	-	-	-
				Spinola Bay area, Sliema		Lower Coralline Limestone coastline with concrete patches	-	Isolated	-	-	-	-
						Wooden fishing boat	-	<10	-	-	-	-

	Balluta	Concrete wall	-	<10	-	-	-	-
	Sliema Seafront, Sliema	Lower Globigerina Limestone coastline	-	~50	-	-	-	-
	Qui-si-sana, Sliema	Lower Globigerina Limestone coastline	-	~10 to ~100	-	-	-	-
	Tignè Point, Sliema	Lower Globigerina Limestone coastline	-	~10 to ~100	-	-	-	-
	Tà Xbiex	Lower Globigerina Limestone coastline	-	~100	-	-	-	-
			-	<10	-	-	-	-
	Pietà Safront	Concrete wall	-	<10	-	-	-	-
	Xatt it-Tiben, Sa Maison	Concrete slope	-	~50	-	-	-	-
	Fort St Elmo area (Marsamxett), Valletta	Lower Globigerina Limestone coastline	-	~10	-	-	-	-
	Tà Liesse area, Valletta	Isolated Lower Globigerina Limestone patch	-	~10	-	-	-	-
	Xghajra–Marsaskala stretch	Lower Globigerina Limestone coastline	-	~10 to ~100	-	-	-	-
			-	Isolated	-	-	-	-
		Weathered/eroded concrete platform	-	Scattered	-	-	-	-
		Lower Globigerina Limestone coastline	-	~10 m2 to ~100 m2	-	-	-	-

	Tal-Mig˙nuna Cliffs, Marsakala	Middle/Lower Globigerina Limestone coastline	-	~10 to ~100	-	-	-	-
	St. Thomas' Bay area, Birzebbuga	Middle/Lower Globigerina Limestone coastline	-	>1000	-	-	-	-
		Concrete wall	-	~100				
		Sand	-	~10				
	Xrobb l-Ghagin, Delimara	Upper Globigerina Limestone coastline, with occasional Middle and Lower Globigerina, Limestone outcrops	-	Scattered	-	-	-	-
	San Lucian promontory, Qajjenza, Birzebbuga	Concrete wall (relatively smooth)	-	Scattered	-	-	-	-
		Upper Globigerina Limestone coastline, with occasional Middle and Lower Globigerina, Limestone outcrops	-	Scattered	-	-	-	-
		-	-	>1000	-	-	-	-
		-	-	<10	-	-	-	-
		Middle and Upper Globigerina Limestone	-	100 to 1000	-	-	-	-

						platform						
				Munxar Point, Birzebbuga		Middle/Lower Globigerina Limestone coastline	-	~100	-	-	-	-
							-	~10	-	-	-	-
							-	Scattered	-	-	-	-
				St George Bay		Upper Globigerina Limestone coastline, with occasional Middle and Lower Globigerina, Limestone outcrops	-	~10	-	-	-	-
							-	~100	-	-	-	-
							-	>1000	-	-	-	-
				Ghar Lapsi main area		Weathered/eroded concrete platform	-	~10	-	-	-	-
				Ghajn Tuffieha to Il-Mixquqa area, Mellieha		Upper coralline Limestone boulder and pebbles	-	~10	-	-	-	-
Bp_19	*B. pharaonis*	E	Turkey	Meydan Köy	Epibiosis	Intertidal rock	Serpulids (*Hydroides brachyacanthus*, *H. diramphus*, *H. elegans*, *H. heterocerus*, *H. homoceros*, *H. minax*, *H. operculatus*, *Pomatoleios kraussii* and *Spirobranchus tetraceros*	-	-			
Bp_20	*B. pharaonis*	E	Turkey	Iskenderun Bay	Associated species		*Pseudonereis anomala*	-	-			
Bp_21	*B. pharaonis*	W	Italy	Calabria (Vibo Valentia)	Checklist	Artificial hard substrate	-	-	-			

				Gulf of Naples		(harbour wall)	-	-	-			
				Gulf of Taranto			-	-	-			
Bp_22	*B. pharaonis*	C	Italy	Calabrian shores	Checklist	Artificial hard substrate - Artificial hard substrate - Fish farming nets	*Mytilaster minimus* - *Mytilus galloprovincialis*- Corallina, Chaetomorpha and Ulva species	200				
Bp_23	*B. pharaonis*	E	Lebanon		Checklist							
Bp_24	*B. pharaonis*	E	Israel	Tel Shiqmona	Associated species	Shallow - intertidal	Flatworm					
Bp_25	*B. pharaonis*	C	Croatia		Checklist						38.5	
Bp_26	*B. pharaonis*	C	Italy	Adriatic Sea (Trieste)	Checklist							
Bp_27	*B. variabilis*	C	Italy	Eastern Sicily	First record							
Bp_28	*B. variabilis*	C	Italy	Eastern Sicily	Checklist							
Bp_29	*B. variabilis*	C	Italy	Sicily - Calabrian coasts	Checklist							
Bp_30	*B. pharaonis*	E	Turkey	Bay of İskenderun Mersin Bay Mugla Province [Iztuzu Dalyan] Anamur-Aydincik Antalya Meydan Koyu Karaburum Peninsula	First record	Shallow - intertidal rocks (natural hard substrata)		>50		20	38.5	
Bp_31	*B. pharaonis*	E	Turkey	Iskenderun Bay Antalya Bay	Epibiosis alien species		*Pachygrapsus marmoratus* - *Pilumnus hirtellus*	beds		27.5	38.5	
Bp_32	*B. pharaonis*	C	Malta		Checklist							

Bp_33	*B. pharaonis*	E	Israel		Biomonitoring MDR transporters	Rocks at waterline		
Bp_34	*B. variabilis*	E	Israel		Checklist			
Bp_35	*B. pharaonis*	E	Israel		Comparative morphology and cytology (mesocosm)			
Bp_36	*B. pharaonis*	E	Israel		Intertidal assemblages description		*Brachidontes pharaonis- Dendropoma petraeum community - Osilinus turbinatus - Pachygrapsus marmoratus - Chiton olivaceus-Actinia aequina - Mytilaster minimus - Mytilus galloprovincialis - Ostrea edulis* and patellids	
Bp_37	*B. variabilis*	E	Egypt		Checklist			
Bp_38	*B. pharaonis*				Review (state of the art)			
Bp_39	*B. pharaonis*				Review (state of the art)			
Bp_40	*B. pharaonis*				Review (state of the art)			
Bp_41	*B. pharaonis*	E	Israel		Distribution, associated fauna list	Rock		Patch
Bp_42	*B. pharaonis*	C	Italy	Sicily, Siracusa	Bioassays for antifouling treatment optimization and management, Biofouling in industrial water systems			

Bp_43	*B. pharaonis*	C	Italy	Sicily (Salina di Marsala)	Associated species		*Ventrosia ventrosa - Pirenella conica - Loripes lacteus - Cerastoderma glaucum - Nassarius costulatus - Conus mediterraneus - Gibbula adansonii - Cerithium vulgatum*				
Bp_44	*B. pharaonis*	C	Italy	Sicily (Salina di Marsala)	First record						
Bp_45	*B. pharaonis*	C	Italy	Sicily (Salina di Marsala)	First record						
Bp_46	*B. pharaonis*	C	Italy	Sicily (Trapani)	Associated species		*Ventrosia ventrosa - Pirenella conica - Loripes lacteus - Cerastoderma glaucum - Nassarius costulatus - Conus mediterraneus - Gibbula adansonii - Cerithium vulgatum*				
Bp_47	*B. pharaonis*	C	Italy	South-Western Sicily	Associated species						
Bp_48	*B. pharaonis*	C	Italy	Western Sicily	First record						
Bp_49	*B. pharaonis*				Review (state of the art)						
Bp_50	*B. pharaonis*	E	Turkey		Bioaccumulation of heavy metals	Intertidal rocky shore			10 / 20		
Bp_51	*B. pharaonis*	E	Lebanon		Checklist						
Bp_52	*B. pharaonis*	E	Turkey	Turkey, Mersin Bay, Mezitli Park	Bioerosive effect	Intertidal - subtidal natural hard substrata rock (limestone)	*Patella* sp	>500 (bed)	10 / 20	20	38.5
Bp_53	*B. pharaonis*	E	Israel		Checklist						

Bp_54	*B. pharaonis*	E	Cyprus		Checklist						
Bp_55	*B. pharaonis*	E	Turkey	Mersin Bay	Heavy metals effects	Intertidal - subtidal natural hard substrata		>500 (bed)	30 / 40	25	35.64
Bp_56	*B. pharaonis*	E	Greece	Cyprus	Inventory alien species state of the art						
Bp_57	*B. pharaonis*	E	Syria - Turkey		Checklist						
Bp_58	*B. variabilis*	E	Greece		Checklist						
Bp_59	*B. variabilis*	C	Malta	Study of sympatric species	Checklist		*Modiolus auriculatus- Mytilaster minimus*	beds			
Bp_60	*B. pharaonis*	E	Turkey		Heavy metals effects						
Bp_61	*B. pharaonis*	C	Italy	Sicily, Stagnone di Marsala Lagoon	Bt-based pesticide effetcs				/ 15		
Bp_62	*B. pharaonis*	C	Italy	Venice Lagoon - Grado	Checklist	Intertidal natural hard substrata				15	28.5
Bp_63	*B. pharaonis*	C	Italy	Sicily, Stagnone di Marsala Lagoon	Inventory alien species state of the art						
Bp_64	*B. pharaonis*	E	Israel	Rosh Haniqra-Akhziv MPA	Checklist	Shallow - Intertidal natural substrata	Green Algae - Vermetus - Barnacles - Limpets			20	38.5
Bp_65	*B. pharaonis*	W	Italy	Corsica	Checklist						
Bp_66	*B. pharaonis*	E	Israel		Predation						
Bp_67	*B. pharaonis*	E	Israel		Competition						
Bp_68	*B. pharaonis*	E	Israel		Checklist						
Bp_69	*B. pharaonis*	C	Malta	Birzebbugia Bay, within Marsaxlokk	Distribution, associated fauna	Rocky shore (Globigerina	*Lepidochitona caprearum - Osilinus*	Dense cluster	3 / 25		

	Harbour	limestone bedrock) - fish-farm rigs	*turbinatus - Tricolia pullus pullus - Gibbula adansonii - Gibbula rarilineata - Gibbula umbilicaris - Rissoa similis - Setia turriculata - Alvania mamillata - Caecum trachea - Cerithium vulgatum - Bittium reticulatum - Columbella rustica - Hexaplex trunculus - Stramonita haemastoma - Nassarius cuvierii - Gibberula philippi - Granulina marginata - Mytilus galloprovincialis - Retusa truncatula - Chrysallida interstincta - Odostomia unidentata - Arca noae - Pinctada radiata - Nucula nitidosa - Chlamys varia - Parvicardium scriptum - Venerupis aurea - Holothuria polii - Paracentrotus lividus - Anemonia viridis - Clibanarius erythropus - Chthamalus stellatus - Crangon crangon - Ligia italica - Pachygrapsus marmoratus - Modiolus barbatus*

Bp_70	*B. pharaonis*	C	Italy	Sicily	Dynamic energy budget parameterisation							
Bp_71	*B. pharaonis*	E	Lebanon	Egypt (Beirut - Batroum)	Biological indicators for cadmium	Shallow - intertidal - subtidal natural hard substrata (rock)		100-500	20 / 35	20	38.5	
Bp_72	*B. pharaonis*	E	Syrian		Hydrocarbon Chlorinated Compounds							
Bp_73	*B. pharaonis*				Inventory alien species state of the art							
Bp_74	*B. pharaonis*	E	Cyprus		Checklist							
Bp_75	*B. pharaonis*	E	Egypt		Checklist							
Bp_76	*B. pharaonis*	E	Israel	Akhziv	*Stramonita haemastoma* predatory effect - mesocosm	Horizontal flat rocks with many incisions and holes (infralittoral boulders)						
Bp_77	*B. pharaonis*	E	Israel	Palmachim	Distribution patterns - density	Narrow and offshore platforms - beachrock - Subtidal bedrock - Subtidal platform walls and boulders	Green Algae - Vermetus - Barnacles - Limpets	Beds - patches	0-10 / 30-40	20	38.5	
				Bat-Yam		Narrow and offshore platforms - Subtidal bedrock - Subtidal		Beds - patches				

		platform walls and boulders		
	Mikhmoret	Intermediate platform - Subtidal platform walls and boulders	Individual - small patches	
	Akhziv	Narrow and offshore platforms - Incisioned-rock - Beachrock - Intertidal walls - Subtidal bedrock - Subtidal platform walls and boulders	Beds - patches - Individual - small patches	
	HaBonim	Narrow and offshore platforms - Horizontal vermetid ledge - Intertidal walls - Subtidal platform walls and boulders	Beds - patches - Individual - small patches	
	Tel-Baruch	Beachrock - Subtidal platform walls and boulders	Patches	

				Shiqmona		Intermediate platform - Subtidal platform walls and boulders		Individual - small patches				
				Atlit		Intermediate platform - Subtidal platform walls and boulders		Individual - small patches				
				Rishpon		Beachrock - Subtidal platform walls and boulders		Patches				
				Olga		Intertidal boulders - Subtidal platform walls and boulders		Small patches				
				Nof-Yam		Intertidal boulders - Subtidal platform walls and boulders		Small patches				
				Bat-Yam		Subtidal bedrock - Subtidal platform walls and boulders		Patches				
Bp_78	*B. pharaonis*				Inventory alien species state of the art							
Bp_79	*B. pharaonis*	E	Israel	Tlul - Port Said [All other Israeli sites are the same of Rilov et al	Competition field study	Intertidal natural hard substratum (rocks)	*Mytilaster minimus* - Green Algae - Vermetus - Barnacles - Limpets	Beds		20	38.5	

				2004]								
Bp_80	*B. variabilis*	E	Israel	Palmachim	Competition field study	seaward-dipping beachrock slabs	*Mytilaster minimus*	Individual - cluster - patch - beds	14 / 16	20	38.5	
Bp_81	*B. pharaonis*	C	Italy	Sicily (Stagnone di Marsala)	Clearance, filtration and ingestion rate	submerged hard substrates	*Laurencia papillosa - Padina pavonica - Acetabularia acetabulum*	patches	/ 30	18.6 ± 7.4	47 ± 4.3	0.8 ± 0.4
Bp_82	*B. pharaonis*	C	Italy	Sicily (Stagnone di Marsala)	Sources of carbon and dietary habits (isotopes analysis)	mediolittoral–upper infralittoral hard substrates (both natural and artificial)	*Chaetomorpha linum, Cystoseira sp., Laurencia papillosa*		20 / 30			
Bp_83	*B. pharaonis*	C	Italy	Sicily	Density and biometrical measures	Intertidal natural and artificial hard substrata	*Mytilaster minimus*	clusters - patches		20		
Bp_84	*B. pharaonis*	C	Italy	Sicily (Stagnone di Marsala)	Integrated isotopic, biochemical and transplant study on the origin and quality of organic matter			9387 ± 4366 (annual mean)				~1.0
Bp_85	*B. pharaonis*	W	Italy	Sicily (Gulf of Castellammare)	Ammonium, Nitrates and Orthophosphates responses	Fouling (fish farm nets)	*Mytilaster minimus - Mytilus galloprovincialis - Modiolus barbatus -* macroalgae		20 /			
Bp_86	*B. pharaonis*	C	Italy	Sicily, Stagnone di Marsala Lagoon	Density - demography - resource allocation		*Cymodeocea nodosa - Laurencia papillosa - Padina pavonica - Acetabularia acetabulum*					

Bp_87	*B. pharaonis*	C	Italy	Sicily, Stagnone di Marsala Lagoon	Absorbtion efficency Temp Sal effects (mesocosm)						
Bp_88	*B. pharaonis*	W	Italy	Sicily (Capo Plaia, Cefalù)	Heart beat rate adaptations to varying salinity (mesocosm)	Rocks at waterline	*Mytilaster minimus*	Beds		22.0 ± 0.5	37.4
				Marsala Lagoon							40
Bp_89	*B. pharaonis*				Modelling						
Bp_90	*B. pharaonis*				Modelling						
Bp_91	*B. pharaonis*				Modelling - Climate change - Ecophysiological study review						
Bp_92	*B. pharaonis*	C	Malta		Inventory alien species state of the art						
Bp_93	*B. pharaonis*	E	Israel	Achziv	Molecular study						
				Shemen							
				Tel Shiqmona							
				Ashqelon							
Bp_94	*B. pharaonis*	E	Lebanon	Beirut area		Intertidal natural and artificial hard substrata			10 / 20	20	38.5
Bp_95	*B. pharaonis*	E	Greece		Checklist						
Bp_96	*B. pharaonis*	W	Italy	Sicily (Stagnone di Marsala)	Genetic variation study (molecular phylogeography)						
Bp_97	*B. pharaonis*	W	Italy	Sicily (Salina di Marsala)	Analysis of molecular variance	-					

				Sicily (Termini Imerese)	(mitocondrial COI sequences)	-		
				Sicily (Torre Normanna)		-		
				Sicily (Capo D'Orlando)		-		
Bp_98	*B. variabilis*	E	Turkey		Heavy metal accumulation (mesocosm)			Beds
Bp_99	*B. pharaonis*	C	Italy	Trieste	Checklist			
Bp_100	*B. pharaonis*	C	Italy	Trieste	Checklist			
Bp_101	*B. pharaonis*	C	Italy	Sicily (Trapani, Saline Ettore-Infersa)	Cytogenetic characterization (molecular study)	Sandstone cubic boulders		
Bp_102	*B. pharaonis*	C	Malta	Il-Qajjenza (Marsaxlokk Bay)	species coexistence	(Artifical hard substrate) fish farm buoys fouling	Ascidians, bryozoans, algae, sessile polychaetes and bivalves	
Bp_103	*B. variabilis*	C	Italy	Calabrian coast	First record			
Bp_104	*B. pharaonis*				Review			
Bp_105	*B. pharaonis*	E	Greece		Inventory alien species state of the art			
Bp_106	*B. pharaonis*	E	Lebanon		Checklist			

Bp_1	Abi-Ghanem C., Khalaf G., and Najjar E. 2014. Distribution of Lead, Cadmium, and Vanadium in Lebanese Coastal Sediments and Mussels. Journal of Coastal Research 30(5):1074-1080
Bp_2	Açik Ş. 2008. Occurrence of the alien species Aspidosiphon (Aspidosiphon) elegans (Sipuncula) on the levantine and aegean coasts of Turkey. Turkish Journal of Zoology 32(4):443-448
Bp_3	Arcidiacono A, and Di Geronimo I. 1976. Studio biometrico di alcuni campioni di Brachidontes variabilis (Krauss). Conchiglie 12(3-4):61-74
Bp_4	Arizza A., Zenone A., Giaramita F.T., Rinaldi A., Sarà G. 2008. Heat shock proteins (HSP) in Brachidontes pharaonis (Mollusca, Bivalvia) at varying temperatures. Biologia Marina Mediterranea 15(1):404-405
Bp_5	Barash A. and Danin, Z. 1992. Fauna Palaestina: Mollusca I. Annotated list of Mediterranean molluscs of Israel and Sinai. The Israel Academy of Sciences and Humanities, Jerusalem
Bp_6	Bitar G., Dupuy de la Grandrive R., Foulquié M. 2003. Second mission relating to the Development of Marine Protected Areas on Syrian coasts, 1-18 August 2003. Mission Report. Regional Project for the Development of Marine and Coastal Protected Areas in the Mediterranean Region. UNEP pp. 40
Bp_7	Bitar G. 2014. Exotic molluscs from the Lebanese coast. Bulletin de la Société zoologique de France 139(1-4):37-45
Bp_8	Bonnici L., Evans J., Borg J.A:, Schembri P.J. 2012. Biological aspects and ecological effects of a bed of the invasive non-indigenous mussel Brachidontes pharaonis (Fischer P., 1870) in Malta. Mediterranean Marine Science 13(1):153-161
Bp_9	Bresler V., Abelson. A., Feldstein T., Mokady O., Fishelson L., Rosenfeld M. 2003. Marine molluscs in environmental monitoring I. Cellular and molecular responses. Helgoland Marine Research 57(3-4):157-165
Bp_10	Boudouresque C.F. 1999. The Red Sea - Mediterranean link: unwanted effects of canals. Invasive Species and Biodiversity Management, Kluwer Academic Publishers, Dordrecht, the Netherlands
Bp_11	Buzzurro G., Greppi E. 1996. The Lessepsian molluscs of Taşucu (South-East Turkey). La Conchiglia 28(279):3-22
Bp_12	Buzzurro G., Greppi E. 1997. Note e considerazioni sui molluschi di Cipro con particolare riguardo alle specie alloctone. La Conchiglia 29(283):21-31
Bp_13	Carlier A. 2007. Apports des isotopes stables a la description de l'architecture et du fonctionnement des réseaux trophiques benthiques de plusieurs environnements côtiers du Golfe du Lion (Méditerranée Nord Occidentale). PhD Thesis, Université Pierre et Marie Curie - Paris 6, Paris. 201 pp
Bp_14	Carlier A., Riera P., Amouroux J.M., Bodiou J.Y., Desmalades M., Grémare A. 2009. Spatial heterogeneity in the food web of a heavily modified Mediterranean coastal lagoon: stable isotope evidence. Aquatic Biology 5:167-179
Bp_15	Caruso M., Romano C., Sarà G. 1999. Seston food availability for suspension feeder molluscs in two areas with different hidrodinamic features. Biologia Marina Mediterranea 6(1)
Bp_16	Cecalupo A., Quadri P. 1996. Contributo alla conoscenza malacologica per il nord dell'isola di Cipro (Terza e ultima parte). Bollettino Malacologico 31(5-8):95-118
Bp_17	Çevik C., Erkol I.L., Toklu B. 2006. A new record of an alien jellyfish from the Levantine coast of Turkey - Cassiopea andromeda (Forsskål, 1775) [Cnidaria: Scyphozoa: Rhizostomea]. Aquatic Invasions 1:196-197
Bp_18	Cilia D.P., Deidun A. 2012. Branching out: Mapping the spatial expansion of the lessepsian invader mytilid Brachidontes pharaonis around the Maltese Islands. Marine Biodiversity Records e(e28):1-8
Bp_19	Çinar M.E. 2006. Serpulid species (Polychaeta: Serpulidae) from the Levantine coast of Turkey (eastern Mediterranean), with special emphasis on alien species. Aquatic Invasions 1(4):223-240
Bp_20	Çinar M.E., Altun C 2007. A preliminary study on the population characteristics of the Lessepsian species Pseudonereis anomala (Polychaeta: Nereididae) in İskenderun Bay (Levantine Sea, Eastern Mediterranean). Turkish Journal of Zoology 31(4):403-410
Bp_21	Crocetta F., Renda W., Colamonaco G. 2009. New distributional and ecological data of some marine alien molluscs along the southern Italian coasts. Marine Biodiversity Records 2(e23):1-7
Bp_22	Crocetta F., W. Renda, Vazzana A. 2009. Alien Mollusca along the Calabrian shores of the Messina Strait area and a review of their distribution in the Italian seas. Bollettino Malacologico 45(1):15-30
Bp_23	Crocetta F., Bitar G., Zibrowius H., Oliverio M. 2013. Biogeographical homogeneity in the eastern Mediterranean Sea. II. Temporal variation in Lebanese bivalve biota. Aquatic Biology 19(1):75-109
Bp_24	Curini-Galletti M., Campus P. 2007. Boninia neotethydis sp. nov. (Platyhelminthes: Polycladida: Cotylea)—the first lessepsian flatworm. Journal Marine Biolpgical Association UK 87:435–442

Bp_25 De Min R., Vio E. 1997. Molluschi conchiferi del litorale sloveno. Annals for Istrian and Mediterranean Studies, Koper, Historia Naturalis 11:241-258

Bp_26 De Min R., Vio E. 1998. Molluschi esotici nell'Alto Adriatico. Annales. Series historia naturalis

Bp_27 Di Geronimo I. 1971. Prima segnalazione sulle costa italiane di Brachidontes variabilis (Krauss). Bollettino delle sedute dell'Accademia Gioenia di scienze naturali in Catania 10:847-852

Bp_28 Di Geronimo I. 1971. Molluschi rari o nuovi per le coste orientali della Sicilia. Conchiglie 7(5-6):61-72

Bp_29 Di Natale A. 1982. Extra-Mediterranean species of Mollusca along the Southern Italian Coasts. Malacologia 22(1-2):578-580

Bp_30 Doğan A., Önen M., Öztürk B. 2007. A new record of the invasive Red Sea mussel Brachidontes pharaonis (Fischer P., 1870) (Bivalvia: Mytilidae) from the Turkish coasts. Aquatic Invasions 2(4):461-463

Bp_31 Dogan A., Azcan T., Bakir K., Kataga T. 2008. Crustacea Decapoda associated with Brachidontes pharaonis (P. Fischer, 1870) (Mollusca, Bivalvia) beds from the Levantine coasts of Turkey. Crustaceana 81(11):1357-1366

Bp_32 Evans J., Barbara, J., Schembri P.J. 2015.Updated review of marine alien species and other 'newcomers' recorded from the Maltese Islands (Central Mediterranean). Mediterranean Marine Science 16(1):225-244

Bp_33 Feldstein T., Nelson N., Mokady O. 2006. Cloning and expression of MDR transporters from marine bivalves, and their potential use in biomonitoring. Marine Environmental Research 62:118-121

Bp_34 Felsenburg T., Safriel U. 1974. Colonization of eastern Mediterranean intertidal zone by Indo-pacific mussel, Brachidontes variabilis. Israel Journal of Zoology 23:212-213

Bp_35 Fishelson L. 2000. Comparative morphology and cytology of siphons and siphonal sensory organs in selected bivalve molluscs. Marine Biology 137(3):497-509

Bp_36 Fishelson L. 2000. Marine animal assemblages along the littoral of the Israeli Mediterranean seashore: The Red Mediterranean Seas communities of species. Italian Journal of Zoology 67(4):393-415

Bp_37 Fuchs Th. 1978. Die geologische Beschaffenheit der Landenge von Suez. Denkschriften der Kaiserkichen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Classe 38:25

Bp_38 Galil B.S. 2007. Loss or gain? Invasive aliens and biodiversity in the Mediterranean Sea. Marine Pollution Bulletin 55(7–9):314–322

Bp_39 Galil B.S. 2007. Seeing Red: Alien species along the Mediterranean coast of Israel. Aquatic Invasions 2(4):281-312

Bp_40 Galil B.S. 2008. Alien species in the Mediterranean Sea - Which, when, where, why? Hydrobiologia 606(1):105-116

Bp_41 Galil B., Gertman I., Nurit G., Barak H., Israel A., Lubinevsky H., Rilov G., Rinkevich B. 2013. Biodiversity monitoring along the Israeli coast of the Mediterranean - activities and accumulated data. Israel Oceanographic and Limnological Research contribution (IOLR Report)

Bp_42 Garaventa F., Corra C., Piazza V., Giacco E., Greco G., Pane L., Faimali M. 2012. Settlement of the alien mollusc Brachidontes pharaonis in a Mediterranean industrial plant: Bioassays for antifouling treatment optimization and management. Marine Environmental Research 76:90-6

Bp_43 Gianguzza P., Chemello R., Cicciari A., Riggio S. 1997. Struttura del popolamento a molluschi della vasca di fredda di una salina marsalese. Biologia Marina Mediterranea 4(1):396-398

Bp_44 Gianguzza P., Chemello R., Riggio S. 1998. Segnalazione di Brachidontes pharaonis (P. Fischer, 1870) (Bivalvia, Mytilidae) nella salina di Marsala e considerazioni sulla distribuzione della specie in Mediterraneo. Bollettino Malacologico 33(9-12):169-172

Bp_45 Gianguzza P., Sarà G., Chemello R., Riggio S. 1998. Note su una popolazione a Brachidontes pharaonis (Fischer P.) (Bivalvia, Mytilidae) in una Salina marsalese. Biologia Marina Mediterranea 5(1):561-562

Bp_46 Gianguzza P., Zava B., Riggio S. 2001. Descrizione del popolamento a molluschi della salina "Grande" di Trapani e Paceco (Tp, Sicilia). XIII S. It. E. Congress. Como, Italy. Ecologia, Edited by: Casagrandi, R. and Melià, P.

Bp_47 Gianguzza P., Chemello R., Riggio S. Composizione e struttura della malacofauna di una salina della Sicilia occidentale. Bollettino Malacologico 36(9-12):201-207

Bp_48 Gianguzza P. 2001. Nuova segnalazione di Brachidontes pharaonis (Fischer P., 1870) (Bivalvia, Mytilidae) lungo le coste della Sicilia occidentale. Biogeographia XXII:259-262

Bp_49 Gofas S., Zenetos A. 2003. Exotic molluscs in the Mediterranean basin: Current status and perspectives. Oceanography and Marine Biology 41:237-277

Bp_50 Goksu M.Z.L., Akar M., .Cevik F., Findik O. 2005. Bioaccumulation of some heavy metals (Cd, Fe, Zn, Cu) in two Bivalvia species (Pinctada radiata Leach, 1814 and Brachidontes pharaonis Fischer, 1870). Turk J Vet Anim Sci 29:89-93

Bp_51 Gruvel A., Moazzo G. 1931. Contribution à la faune malacologique marine des côtes Libano-Syriennes. Gruvel A. (ed.), Les états de Syrie. Richesses marines et fluviales. Société des Editions Géographiques, Maritimes et Coloniales, Paris

Bp_52 Guel M., Oezbek A., Karayakar F., Kurt A. 2008. Biodegradation effects over different types of coastal rocks. Environmental Geology 55:1601-1611

Bp_53 Haas G. 1937. Mollusca marina, in F.S. Bodenheimer, Prodromus Faunae Palestinae. Mem. Inst. Egypte 33:275-280

Bp_54 Hadjichristophorou M., Argyrou M., Demetropulos A., Bianchi T.S. 1997. A species list of the sublittoral soft-bottom macrobenthos of Cyprus. Acta Adriatica 38(1):3-32

Bp_55 Karayakar F., Erdem C., Cicik B. 2007. Seasonal variation in copper, zinc, chromium, lead and cadmium levels in hepatopancreas, gill and muscle tissues of the mussel Brachidontes pharaonis Fischer, collected along the Mersin coast, Turkey. Bulletin of Environmental Contamination and Toxicology 79(3):350-355

Bp_56 Katsanevakis S., Tsiamis K., Ioannou G., Michailidis N., Zenetos A. 2005. Inventory of alien marine species of Cyprus. Mediterranean Marine Science 10(2):109-113

Bp_57 Kinzelbach R. 1985. Lesseps'sche Wanderung: neue stationen von Muscheln (Bivalvia: Anisomyaria). Archiv fur Molluskenkunde 115(4-6):273-278

Bp_58 Koroneos J. 1979. Les Mollusques de la Grèce. Athènes 36:48

Bp_59 Lanfranco G. 1975. Some additions to the local Mollusca. The Maltese Naturalist 2,27

Bp_60 Leach P., Fischer B. 2005. Bioaccumulation of Some Heavy Metals (Cd , Fe , Zn , Cu) in Two Bivalvia Species. Turk J VetAnim Sc 29:89-93

Bp_61 Manachini B., Arizza V., Rinaldi A., Montalto V., Sarà G. 2013. Eco-physiological response of two marine bivalves to acute exposition to commercial Bt-based pesticide. Marine Environmental Research 83:29-37

Bp_62 Marchini A., Marchini C. 2006. A fuzzy logic model to recognise ecological sectors in the lagoon of Venice based on the benthic community. Ecological Modelling 193:105–118

Bp_63 Mazzola A., Vizzini S. 2005. Caratteristiche ecologiche, fattori di pressione antropica e sviluppo sostenibile di un ambiente costiero mediterraneo (Stagnone di Marsala, Sicilia Occidentale). Naturalista Siciliano IV, XXIX (1-2), 37-65.

Bp_64 MedMPA. 2004. Marine Biodiversity Study of the Rosh Haniqra-Akhziv Nature Reserves (Israel) to the Establishment of a Management Plan. Regional Project for the Development of Marine and Coastal Protected Areas in the Mediterranean Region (MedMPA). Final report

Bp_65 Merella P., Porcheddu A., Casu S. 1994. La malacofauna della riserva naturale di Scandola (Corsica Nord-occidentale). Bollettino Malacologico 30(5-9):111-128

Bp_66 Mienis H.K. 2002. A case of predation on mussels by the hite Sea Bream. Spirula 325:27

Bp_67 Mienis H.K. 2003. Native marine molluscs replaced by Lessepsian migrants. Tentacle 11:15-16

Bp_68 Mienis H.K. 2004. New data concerning the presence of Lessepsian and other indo-pacific migrants among the mollusca in the Mediterranean Sea with emphasize on the situation in Israel. 1st National Malacology Congress

Bp_69 Mifsud C., Cilia D.P. 2009. On the presence of a colony of Brachidontes pharaonis (P. Fischer, 1870) (Bivalvia : Mytilidae) in maltese waters (Central Mediterranean). Triton 20:1-2

Bp_70 Montalto, V., Palmeri V., Rinaldi A., Kooijman S.A.L.M and G. Sarà. 2014. Dynamic energy budget parameterisation of Brachidontes pharaonis, a Lessepsian bivalve in the Mediterranean Sea. Journal of Sea Research 94:47-51

Bp_71 Nakhle K. F., Cossa D., Khalaf G., Beliaeff B. 2006. Brachidontes variabilis and Patella sp as quantitative biological indicators for cadmium, lead and mercury in the Lebanese coastal waters. Environmental Pollution 142(1):73-82

Bp_72 Noureddin S., Ali H.K., Ammar I., Abbass G., Baker M., Arabiah I., Abdow O. 2011. Using an International Monitoring Net for Hydrocarbon Chlorinated Compounds at Syrian Sea Water. Tishreen University Journal for Research and Scientific Studies - Basic Sciences Series 33(1):121-138

Bp_73 Occhipinti-ambrogi A., Galil B. 2010. Marine alien species as an aspect of global change. Advances in Oceanography and Limnology 1(1): 199-218

Bp_74 Öztürk B., Buzzurro G., Avni Benli H. 2004. Marine molluscs from Cyprus: new data and checklist. Bollettino Malacologico 39(5-8):49-78

Bp_75 Pallary P. 1912. Catalogue des mollusques du littoral méditerranéen de l'Egypte. Mém. Inst. Egypte 7:69-207

Bp_76 Rilov G., Gasith A., Benayahu Y. 2002. Effect of an exotic prey on the feeding pattern of a predatory snail. Marine Environmental Research 54(1):85-98

Bp_77 Rilov G., Benayahu Y., Gasith A. 2004. Prolonged lag in population outbreak of an invasive mussel: a shifting-habitat model. Biological Invasions 6:347-364

Bp_78 Rilov G., Galil B. 2009. Marine Bioinvasions in the Mediterranean Sea – History, Distribution and Ecology. Chapter 31 in Biological Invasions in Marine Ecosystems (book) Olyarnik S.V., Bracken M.E.S., Byrnes J.E., Hughes R., Hultgren K.M., Stachowicz J.J., Rilov G., Crooks J., Caldwell M.M., Heldmaier G., Jackson R.B., Lange O.L., Mooney H., Schulze E.D., Sommer U. eds

Bp_79 Safriel U.N., Gilboa A., Felsenburg T. 1980. Distribution of Rocky Intertidal Mussels in the Red Sea Coasts of Sinai, the Suez Canal and the Mediterranean Coast of Israel, with Special Reference to Recent Colonizers. Journal of Biogeography 7(1):39-62

Bp_80 Safriel U.N., Sasson-Frostig Z. 1988. Can colonizing mussel outcompete indigenous mussel? Journal of Experimental Marine Biology and Ecology 117(3):221-226

Bp_81 Sarà G., Romano C. 2000. The new Lessepsian entry Brachidontes pharaonis (Fischer P., 1870) (Bivalvia, Mytilidae) in the western Mediterranean: A physiological analysis under varying natural conditions. Journal of Shellfish Research 19:967-977

Bp_82 Sara G., Vizzini S., Mazzola A. 2003. Sources of carbon and dietary habits of new Lessepsian entry Brachidontes pharaonis (Bivalvia, Mytilidae) in the western Mediterranean. Marine Biology 143(4):713-722

Bp_83 Sarà G., Buffa G. 2004. Density and biometrical features of two co-occurring bivalves (Mytilaster minimus and Brachidontes pharaonis) in Western Sicily (South Tyrrhenian). Proceedings 4° National Symposium CONISMA-AIOL, Terrasini (PA) 2004, p 132

Bp_84 Sarà G. 2006. Hydrodynamic effects on the origin and quality of organic matter for bivalves: an integrated isotopic, biochemical and transplant study. Marine Ecology Progress Series 328:65-73

Bp_85 Sarà G., Lo Martire M., Buffa G., Mannino A.M., Badalamenti F. 2007. The fouling community as an indicator of fish farming impact in Mediterranean. Aquaculture Research 38(1):66-75

Bp_86 Sará G., Romano C., Mazzola A. 2008. A new lessepsian species in the western Mediterranean (Brachidontes pharaonis Bivalvia: Mytilidae): density, resource allocation and biomass. Marine Biodiversity Records 1(e8)

Bp_87 Sarà G., Romano C., Widdows J. Staff F.J. 2008. Effect of salinity and temperature on feeding physiology and scope for growth of an invasive species (Brachidontes pharaonis - MOLLUSCA : BIVALVIA) within the Mediterranean sea. Journal of Experimental Marine Biology and Ecology 363(1-2):130-136

Bp_88 Sara G., de Pirro M. 2011. Heart beat rate adaptations to varying salinity of two intertidal Mediterranean bivalves: The invasive Brachidontes pharaonis and the native Mytilaster minimus. Italian Journal of Zoology 78(2):193-197

Bp_89 Sara G., Palmeri V., Montalto V., Rinaldi A., Widdows J. 2013. Parameterisation of bivalve functional traits for mechanistic eco-physiological dynamic energy budget (DEB) models. Marine Ecology Progress Series 328:65-73

Bp_90 Sara G., Palmeri V., Montalto V., Rinaldi A., Helmuth B. 2013. Predicting biological invasions in marine habitats through eco-physiological mechanistic models: a case study with the bivalve Brachidontes pharaonis. Diversity and Distributions 19(10):1235-1247

Bp_91 Sara G., Milanese M., Prusina I., Sarà A., Angel D.L., Glamuzina B., Nitzan T., Freeman S., Rinaldi A., Palmeri V., Montalto V., Lo Martire M., Gianguzza P., Arizza V., Lo Brutto S., De Pirro M. , Helmuth B., Murray J. , De Cantis S., Williams G.A. 2004. The impact of climate change on mediterranean intertidal communities: losses in coastal ecosystem integrity and services. Regional Environmental Change 14:S5-17

Bp_92 Sciberras M., Schembri P.J. 2007. A critical review of records of alien marine species from the Maltese Islands and surrounding waters (Central Mediterranean). Mediterranean Marine Science 6(1):41-66

Bp_93 Shefer S., Abelson A., Mokady O., Geffen E. 2004. Red to Mediterranean Sea bioinvasion: natural drift through the Suez Canal, or anthropogenic transport? Molecular Ecology 13(8):2333-2343

Bp_94 Shiber J.G., Shatila T.A. 1978. Lead, cadmium, copper, nickel and iron in limpets, mussels and snails from the coast of ras beirut, lebanon. Marine Envronmental Research 1: 125-134

Bp_95 Tenekides N.S. 1989. On a collection of shells from the Greek seas. Athens: Protopapa Press pp 187

Bp_96 Terranova M.S., Lo Brutto S., Arculeo M., Mitton J.B. 2006. Population structure of Brachidontes pharaonis (P. Fisher, 1870) (Bivalvia, Mytilidae) in the Mediterranean Sea, and evolution of a novel mtDNA polymorphism. Marine Biology 150(1):89-101

Bp_97 Terranova M.S., Lo Brutto S., Arculeo M., Mitton J.B. 2006. A mitochondrial phylogeography of Brachidontes variabilis (Bivalvia : Mytilidae) reveals three cryptic species. Journal of Zoological Systematics and Evolutionary Research 45(4):289-298

Bp_98 Ünsal M. 1984. Accumulation and loss of tin by the mussel. Oceanologica Acta 7(4): 493-498

Bp_99 Vio E., De Min R. 1996. Contributo alla conoscenza dei Molluschi marini del Golfo di Trieste. Atti del Museo Civico di Storia Naturale di Trieste 47:173-232

Bp_100 Vio E., De Min R. 1999. Ritrovamenti malacologici nel Golfo di Trieste. Hydrores Information 16(17):29-34

Bp_101 Vitturi R., Gianguzza P., Colomba M.S., Riggio S. 2000. Hybridization (fish) (Mollusca: Bivalvia: Mytilidae). Ophelia 52(3):213-220

Bp_102 Zammit P.P., Longo C., Schembri P.J. 2009. Occurrence of Paraleucilla magna Klautau et al., 2004 (Porifera: Calcarea) in Malta. Mediterranean Marine Science 10(2):135-138

Bp_103 Zanca M. 1976. Rinvenimento di esemplari di Brachidontes variabilis (Krauss, 1848) lungo la costa ionica della Calabria. Conchiglie 12(7-8):161-162

Bp_104 Zenetos A., Gofas S., Verlaque M., Cinar M.E., Garcia Raso J,E., Bianchi C.N., Morri C., Azzurro E., Bilecenoglu M., Froglia C., Siokou I., Violanti D., Sfriso A., San Martin G., Giangrande A., Katagan T., Ballesteros E., Ramos-Esplà A., Mastrototaro F., Ocana A., Zingone A., Gambi M.C., Streftaris N. 2010. Alien species in the Mediterranean Sea by 2010. A contribution to the application of European Union’s Marine Strategy Framework Directive (MSFD). Part I. Spatial distribution. Mediterranean Marine Science 11(2):381-493

Bp_105 Zenetos A., Koutsogiannopoulos D., Ovalis P., Poursanidis D. 2013. The role played by citizen scientists in monitoring marine alien species in Greece. Cahiers de Biologie Marine 54(3):419-426

Bp_106 Zibrowius H., Bitar, G. 2003. Invertébrés marins exotiques sur la cote du Liban. Lebanese Science Journal 4(1):67-74

APPENDIX 2

Table A1. Predictor environmental variables used in the models, variables short name, data sources, model and spatial resolution.

Variables	Variables short name	Source	Model	Resolution
Surface temperature mean	ts_mean	Medcordex	MED11-CNRM-ALADIN52	~ 12 km
Surface temperature S.D.	ts_std	Medcordex	MED11-CNRM-ALADIN52	~ 12 km
Surface Downward Eastward Wind Stress mean	tauu_mean	Medcordex	MED11-CNRM-ALADIN52	~ 12 km
Surface Downward Eastward Wind Stress S.D.	tauu_std	Medcordex	MED11-CNRM-ALADIN52	~ 12 km
Surface Downward Northward Wind Stress mean	tauv_mean	Medcordex	MED11-CNRM-ALADIN52	~ 12 km
Surface Downward Northward Wind Stress S.D.	tauv_std	Medcordex	MED11-CNRM-ALADIN52	~ 12 km
Salinity mean	sos_mean	Medcordex	NEMOMED 8 v1	~ 10 km
Chlorophyll a mean	chl_mean	Copernicus	OPATM-BFM	~ 6 km

Table A2. Variables considered for use as input into the distribution model and Variance Inflation Factor (VIF) values of the subset of the variables selected for model development.

Variables	Variables short name	VIFs
Salinity mean	sos_mean	3.523947
Surface Downward Eastward Wind Stress mean	tauu_mean	2.413771
Surface Downward Eastward Wind Stress S.D.	tauu_std	2.490110
Surface Downward Northward Wind Stress mean	tauv_mean	1.993681
Surface Downward Northward Wind Stress S.D.	tauv_std	2.323726
Sea Surface temperature mean	ts_mean	4.065276
Sea Surface temperature S.D.	ts_std	2.038435
Chlorophyll a mean	chl_mean	1.769682

Table A3. Relative contributions of each predictor variable to the *B. pharaonis* distribution model for 2030 Scenario 1 and 2050 Scenario 33.

2030		2050	
Variable	**Percent contribution**	**Variable**	**Percent contribution**
Salinity mean -0.5 psu	81.2	Salinity mean +0.5 psu	81.2
Chlorophyll a mean -10%	5.3	Chlorophyll a mean +10%	4.6
Surface temperature mean	5.2	Surface temperature S.D.	4.5
Surface temperature S.D.	4.0	Surface temperature mean	3.7
Surface Downward Eastward Wind Stress S.D.	1.8	Surface Downward Northward Wind Stress S.D.	1.9
Surface Downward Northward Wind Stress S.D.	1.7	Surface Downward Eastward Wind Stress S.D.	1.8
Surface Downward Eastward Wind Stress mean	0.6	Surface Downward Northward Wind Stress mean	1.3
Surface Downward Northward Wind Stress mean	0.2	Surface Downward Eastward Wind Stress mean	0.8

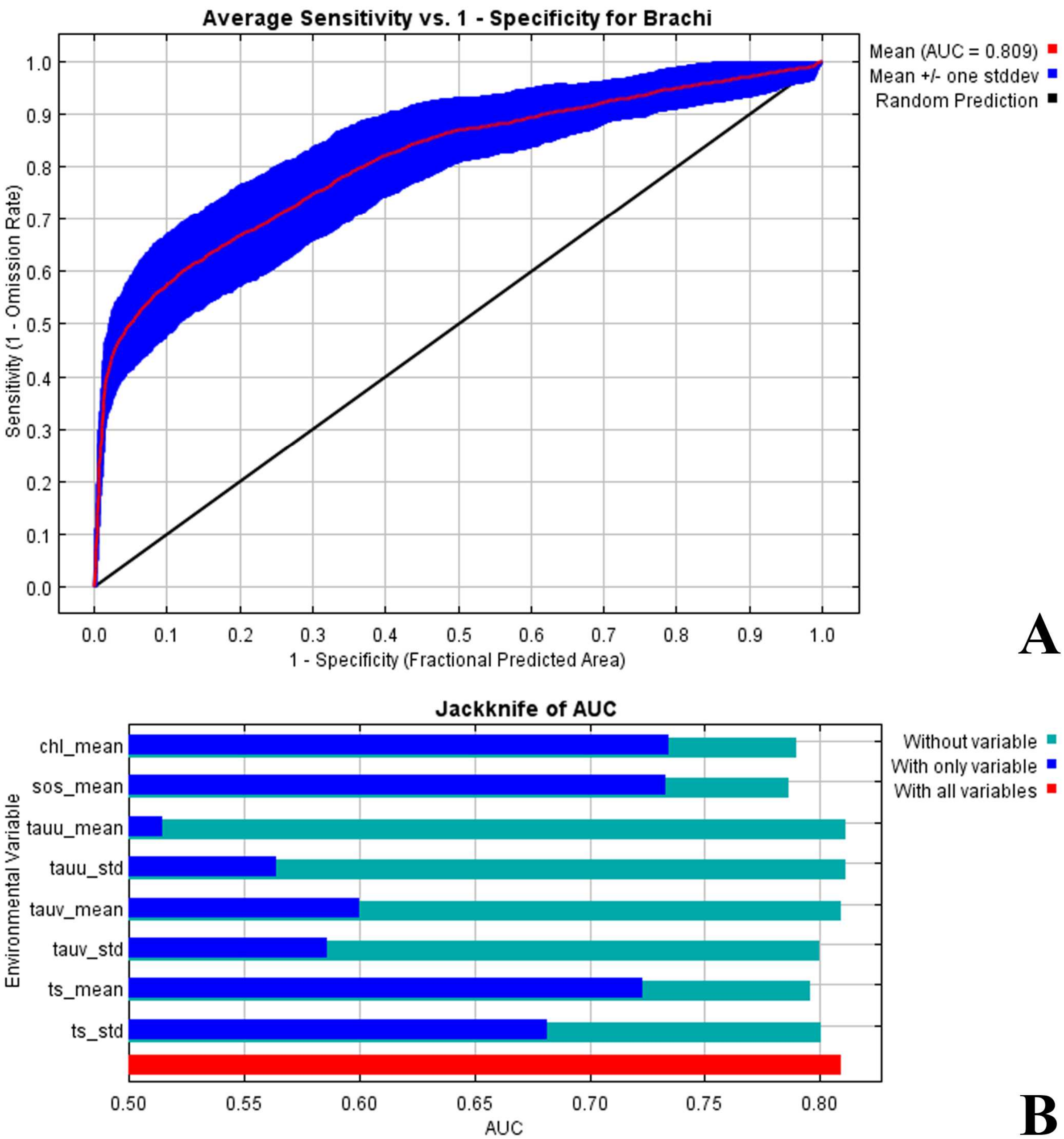


Figure A1. A) ROC (Receiver Operating Characteristic) curves for *B. pharaonis* current models 2010; AUC: Area Under the Curve. B) Jackknife tests of variable importance for the *B. pharaonis* current 2010 distribution model. See Table A2 for full names of environmental variables.

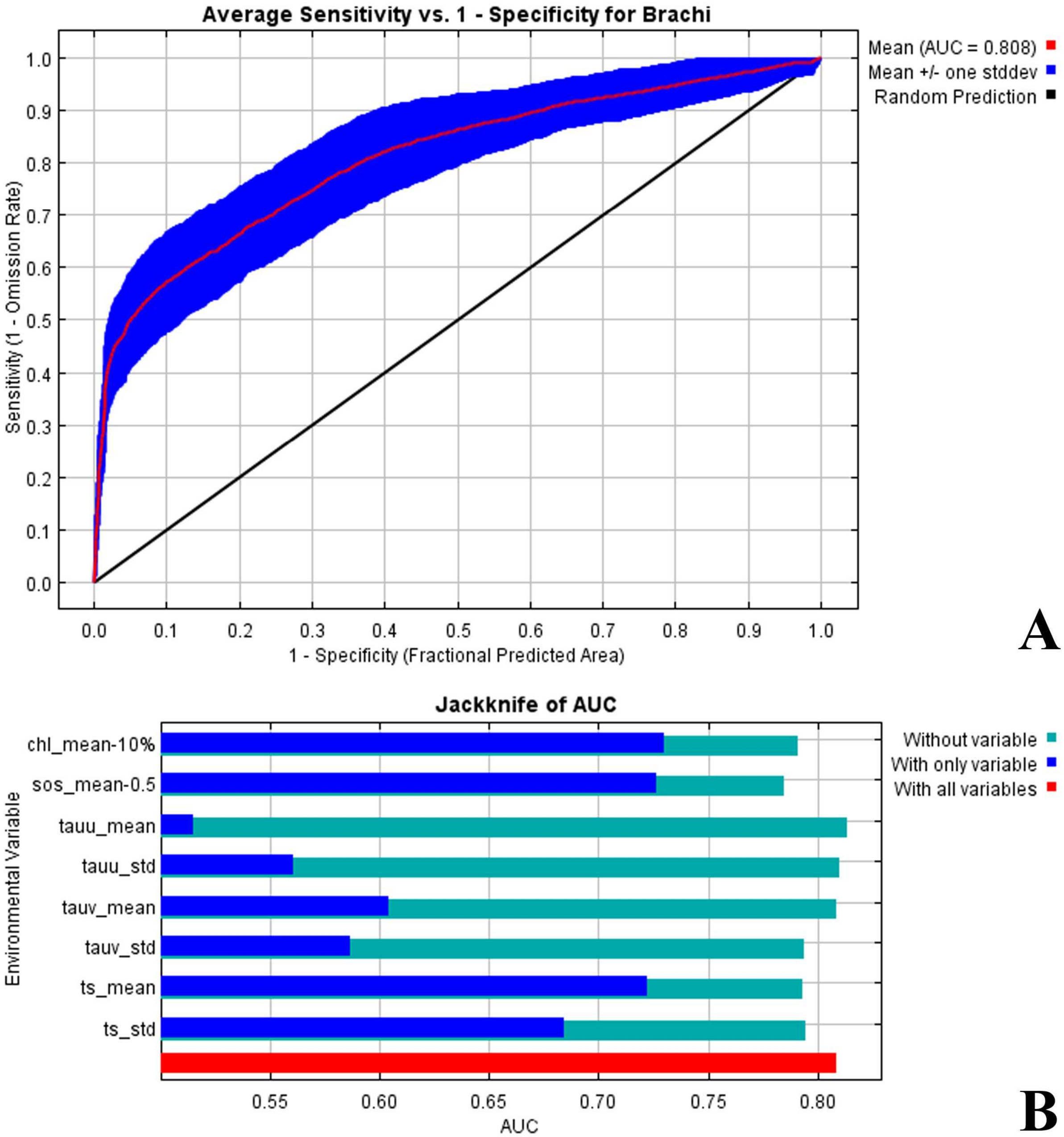


Figure A2. A) ROC (Receiver Operating Characteristic) curves for *B. pharaonis* 2030 Scenario 1 model; AUC: Area Under the Curve. B) Jackknife tests of variable importance for the *B. pharaonis* 2030 distribution model. See Table A2 for full names of environmental variables.

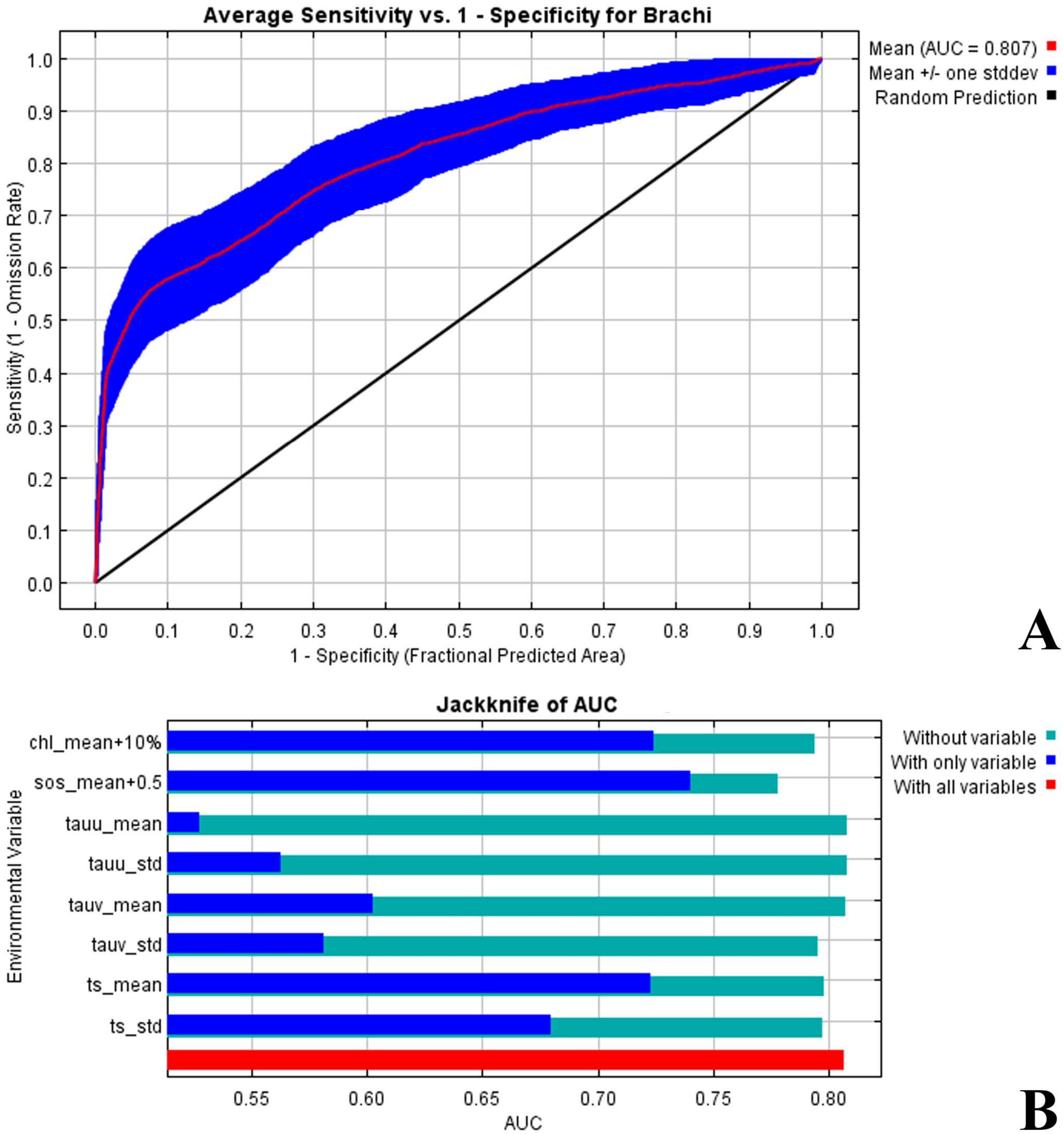


Figure A3. A) ROC (Receiver Operating Characteristic) curves for *B. pharaonis* 2050 Scenario 33 model; AUC: Area Under the Curve. B) Jackknife tests of variable importance for the *B. pharaonis* 2050 distribution model. See Table A2 for full names of environmental variables.

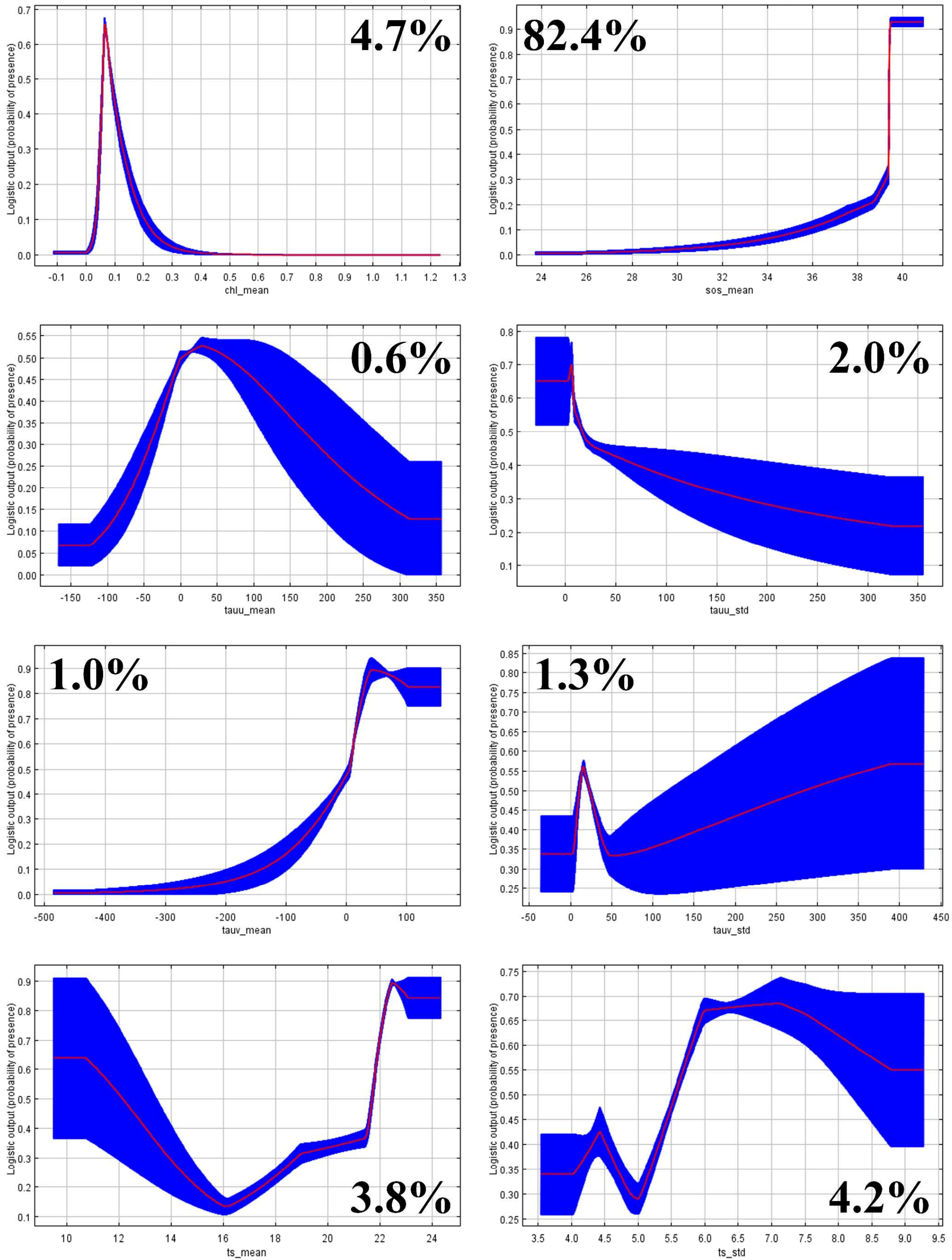


Figure A4. Partial dependence curves of the marginal response of *B. pharaonis* and the importance in percentage of each variable for the 2010 model.

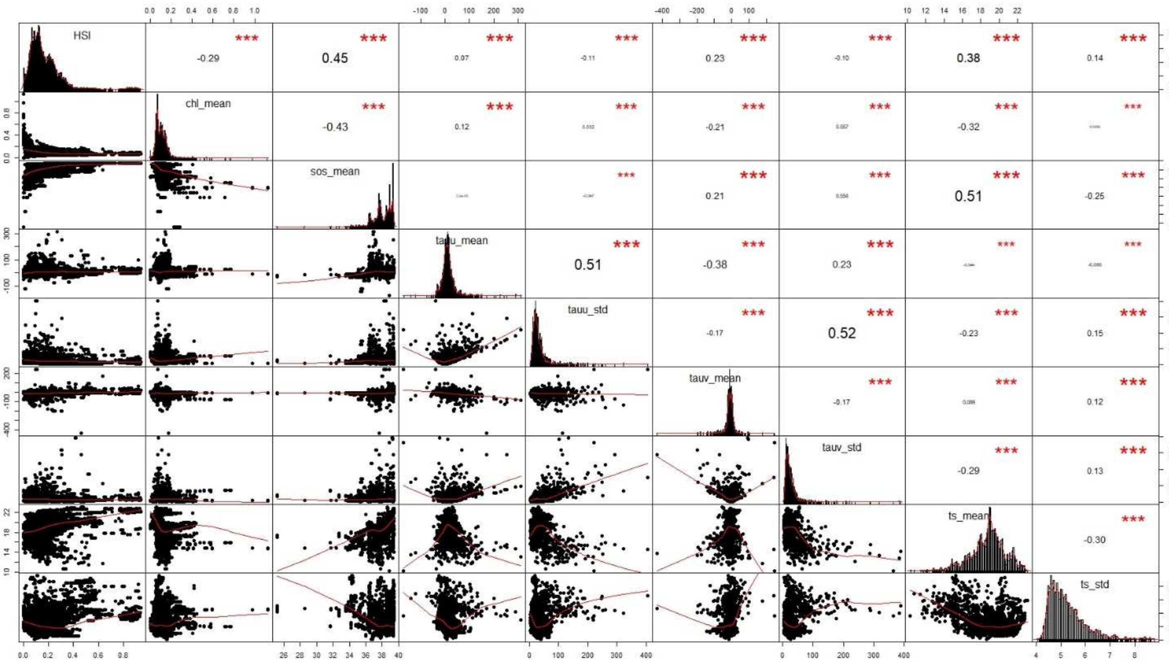
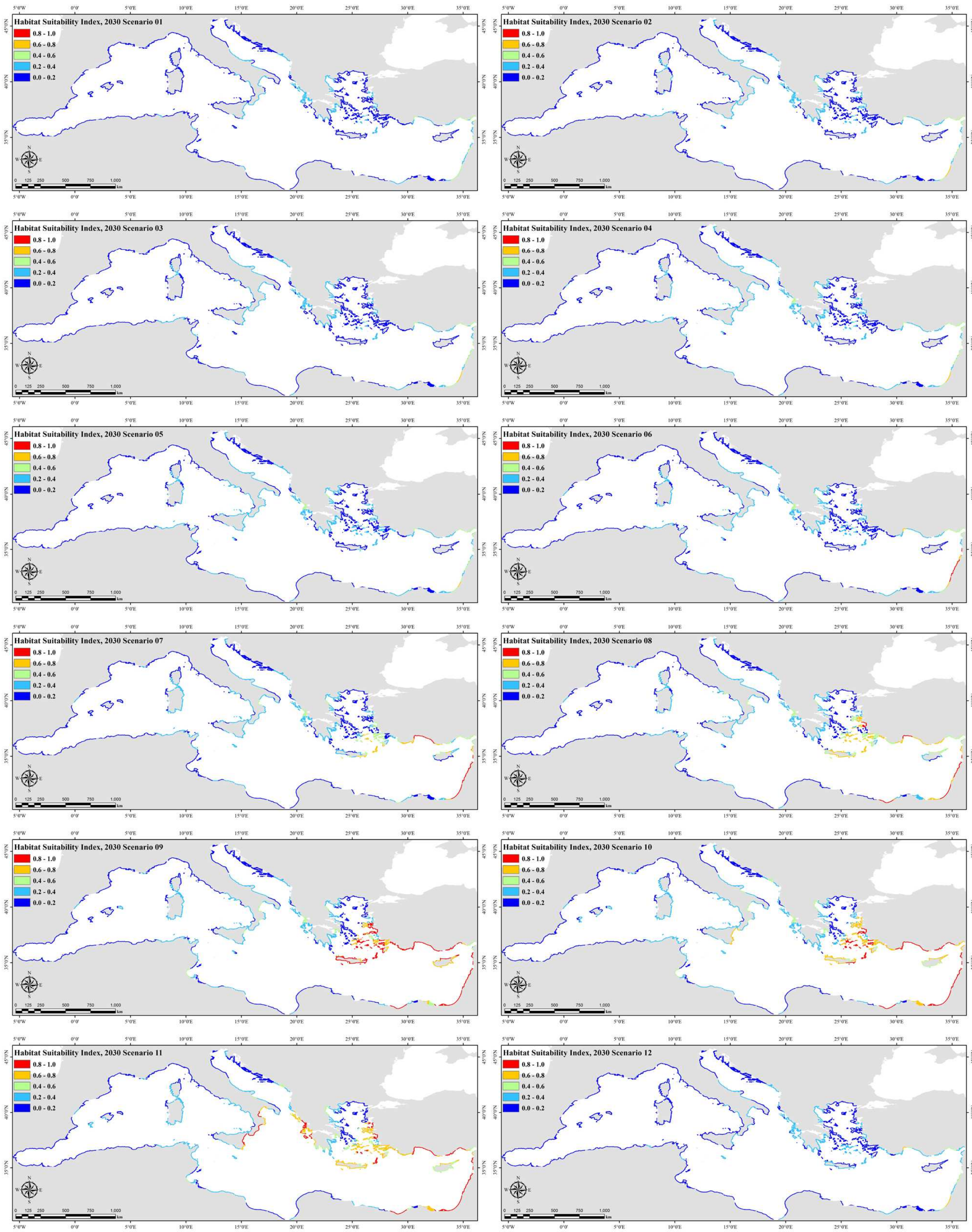
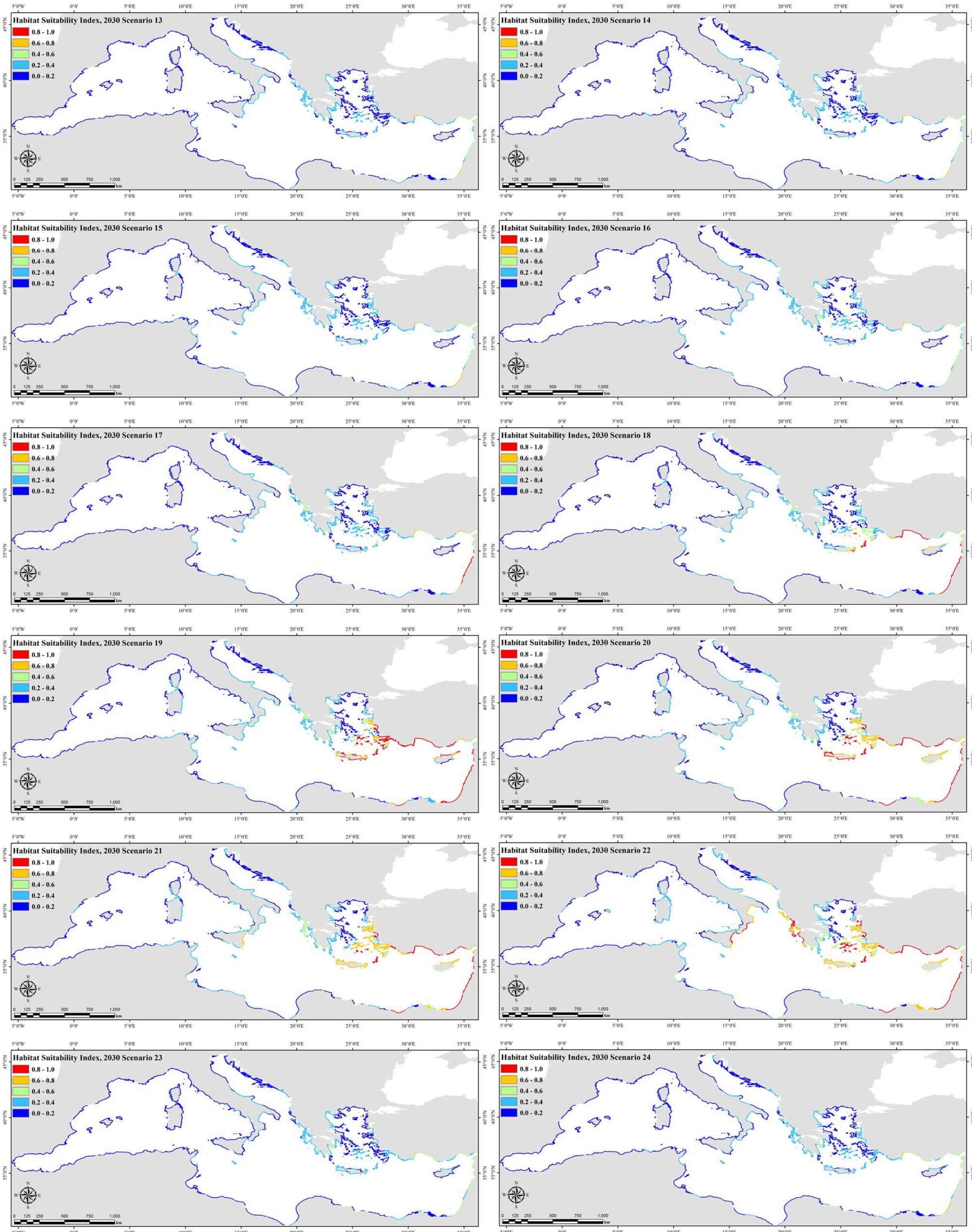


Figure A5. Scatterplot matrix of HSI and the environmental variables considered in 2010 represented to detect correlations between variables. From the top of the panel, are represented absolute Pearson correlations, and significance asterisks (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$), histograms and kernel density overlays. Variables short name are reported in Table A1.


Habitat Suitability Index, 2030 Scenario 01
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 02
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 03
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 04
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 05
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 06
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 07
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 08
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 09
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 10
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 11
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
Habitat Suitability Index, 2030 Scenario 12
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2


Habitat Suitability Index, 2030 Scenario 13
Habitat Suitability Index, 2030 Scenario 14
Habitat Suitability Index, 2030 Scenario 15
Habitat Suitability Index, 2030 Scenario 16
Habitat Suitability Index, 2030 Scenario 17
Habitat Suitability Index, 2030 Scenario 18
Habitat Suitability Index, 2030 Scenario 19
Habitat Suitability Index, 2030 Scenario 20
Habitat Suitability Index, 2030 Scenario 21
Habitat Suitability Index, 2030 Scenario 22
Habitat Suitability Index, 2030 Scenario 23
Habitat Suitability Index, 2030 Scenario 24
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2

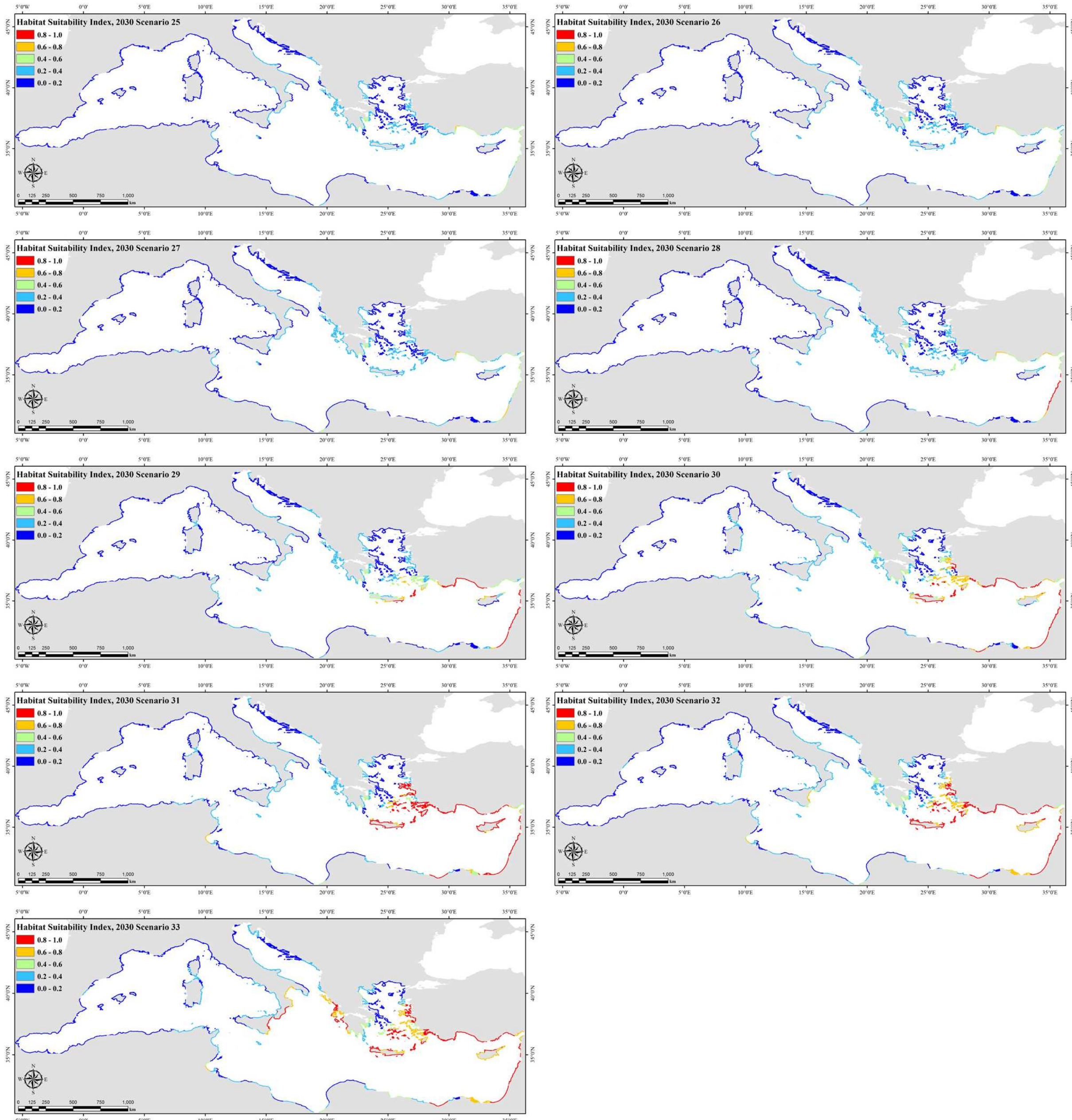
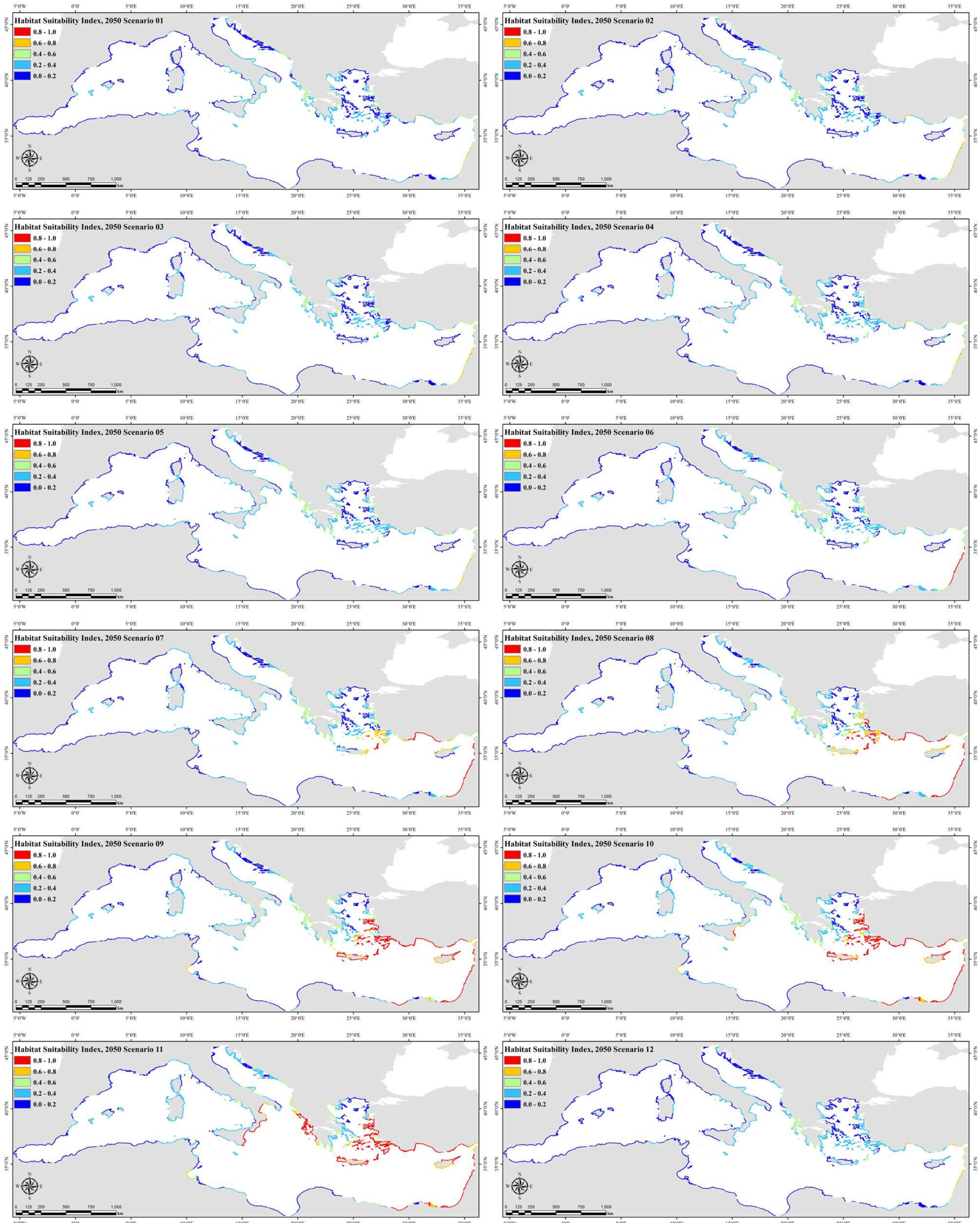
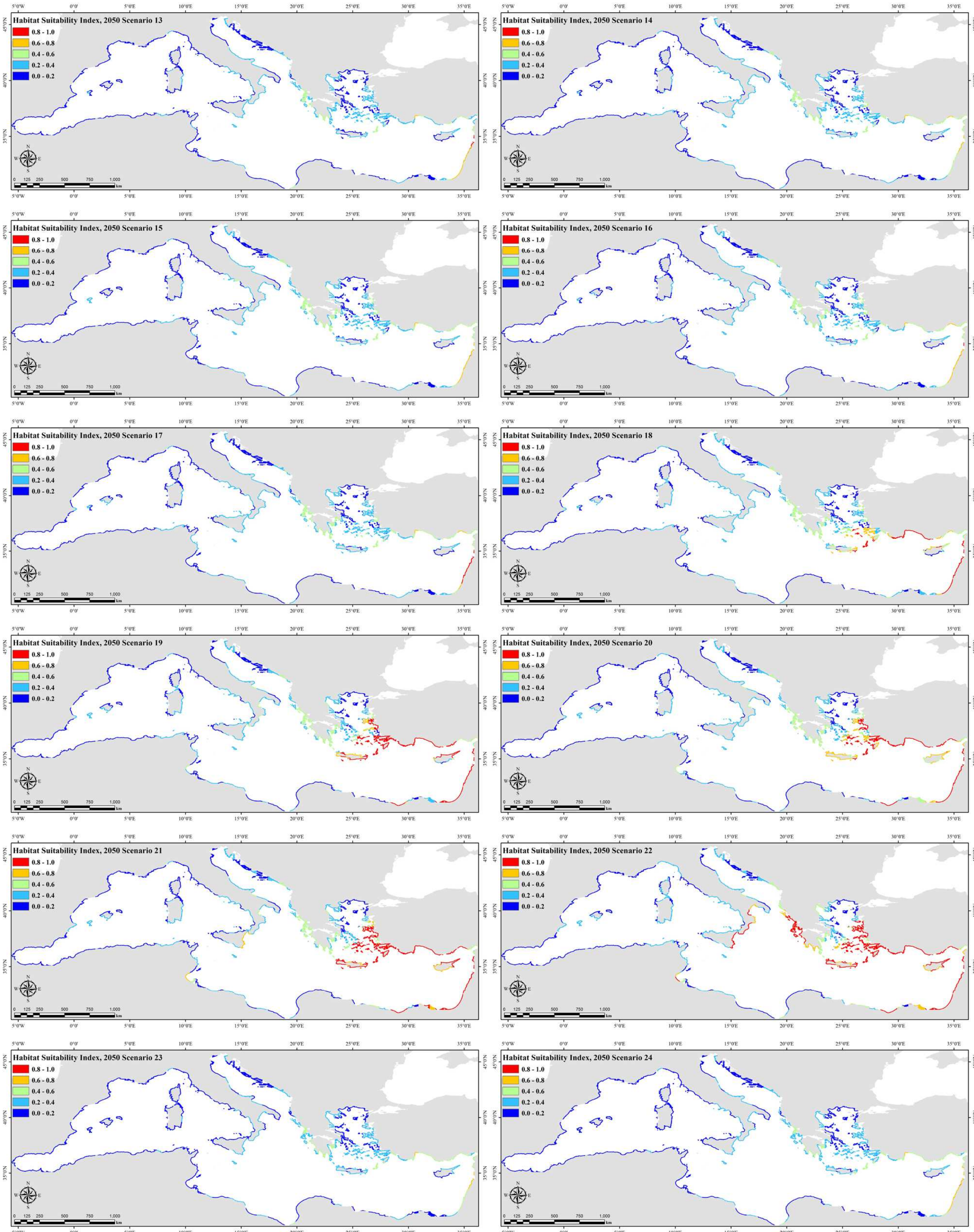


Figure A6. Spatial distributions of predicting suitable habitat of *B. pharaonis* in 2030 for all 33 scenarios considered.


Habitat Suitability Index, 2050 Scenario 01
Habitat Suitability Index, 2050 Scenario 02
Habitat Suitability Index, 2050 Scenario 03
Habitat Suitability Index, 2050 Scenario 04
Habitat Suitability Index, 2050 Scenario 05
Habitat Suitability Index, 2050 Scenario 06
Habitat Suitability Index, 2050 Scenario 07
Habitat Suitability Index, 2050 Scenario 08
Habitat Suitability Index, 2050 Scenario 09
Habitat Suitability Index, 2050 Scenario 10
Habitat Suitability Index, 2050 Scenario 11
Habitat Suitability Index, 2050 Scenario 12
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2
0 125 250 500 750 1,000 km


Habitat Suitability Index, 2050 Scenario 13
Habitat Suitability Index, 2050 Scenario 14
Habitat Suitability Index, 2050 Scenario 15
Habitat Suitability Index, 2050 Scenario 16
Habitat Suitability Index, 2050 Scenario 17
Habitat Suitability Index, 2050 Scenario 18
Habitat Suitability Index, 2050 Scenario 19
Habitat Suitability Index, 2050 Scenario 20
Habitat Suitability Index, 2050 Scenario 21
Habitat Suitability Index, 2050 Scenario 22
Habitat Suitability Index, 2050 Scenario 23
Habitat Suitability Index, 2050 Scenario 24
0.8 - 1.0
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0.0 - 0.2

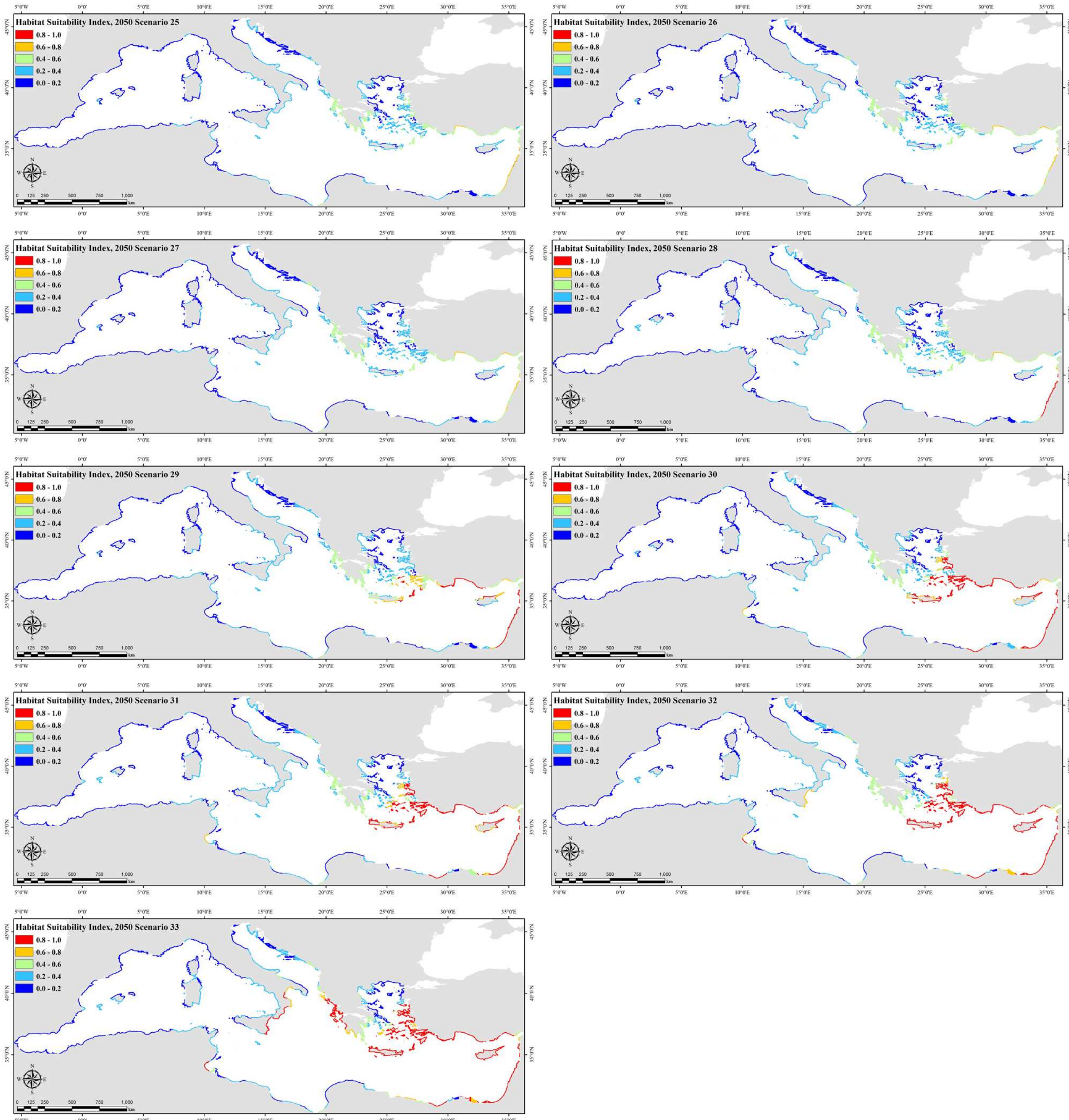


Figure A7. Spatial distributions of predicting suitable habitat of *B. pharaonis* in 2050 for all 33 scenarios considered.